DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Boys will be . . . .

"HAVE fun at the electricity stand" said the announcement of one exhibitor at the Schoolboys' Own Exhibition in London. Eager queues of boys waited to use a concrete drill or have a go with the Dabble or Quit competition. They were urged on leaving not to forget their free copies of a brochure about careers. Dominating the exhibition was a fine integrated working display by the Transport Commission showing trains, lorries, buses, docks and waterways. British Transport, they also happened to point out, is a good concern to work for. Metropolitan Vickers showed working models—one of a generator and one showing a fundamental scientific discovery, the "Hall effect" due to electromagnetic induction. Was it odd that this firm, too, did not fail to show displays connected with apprenticeship schemes? The Armed Forces and the Church of England were there—in their various ways appealing to youth—but amid the high moral appeals, the space guns, the sputnik and many different kinds of working models, we found no trace of a message that plant design or research on chemical processing can also capture youthful imagination.

Reserves Among the Stronger Sex

CAN Britain solve the problem of making good the shortage of qualified engineering personnel for industry by following the Russian practice of recruiting women? This question was raised recently by Professor E. Griffen addressing apprentices of British Oxygen Company subsidiaries at their sixth Annual Prizegiving. Professor Giffen led a delegation to the U.S.S.R. in 1956 to study engineering education. One of the significant things noticed in Russia was the number of women engineering students. About 50% of the engineering students are women. They work at all levels and many are doing jobs of high technical standard with ability. "This is certainly a field that could be tapped in this country. Would women want to do the job and could industry make it worth their while?" Some facts about the corresponding situation in chemistry were given by Miss Olliver in the *Journal of the Royal Institute of Chemistry* (1957, Vol. 81, p. 715). In competing with men for an industrial post, the woman usually finds that she has to be rather better qualified in order to be successful, and when an offer is made, the starting salary is likely to be about 10 or 15% less than that for a man. Furthermore, in all occupational categories the average salary of a woman up to the age of about 35 is 75 to 85% of the corresponding figures for men in the same age groups By the age of 40, the maximum salary of a woman seems to have been reached, and no significant increase is shown up to retiring age. Since men's salaries continue to increase, the difference between the average salaries of men and women in the higher age groups also increases until the woman's salary approximates to only 60% of the man's. In spite of this apparent discrimination Miss Olliver thought it an encouraging sign that the younger woman today is in a more satisfactory position than the older and pioneer woman scientist as regards remuneration and hoped that adequate reward for work done, irrespective of sex, would soon be accepted in principle by industry and other employers, as it is in the Civil Service. We share the hope, not simply on grounds of equity but in order to meet the pressing needs for scientific and engineering personnel.

Underground Gasification in the U.S.S.R.

BY invitation of the Soviet authorities a number of British experts in underground gasification recently visited the Soviet Union. They found three research institutes working on the problems of gasifying coal underground and a number of plants in operation. Rather strangely there was little emphasis on using oxygen-enriched air. At Lisichansk some 20 million cubic feet of gas are produced per day by this technique but the process continues only because the large oxygen plant there has a regular sale for the by-products—argon, krypton and xenon. The use of oxygen and steam enriched air blasts is being studied but broadly the Soviet technicians find it cheaper to export electricity made from gas of low calorific value than to enrich the blast to produce the higher C.V. gas which would justify the cost of pumping more than 15-20 Km. The low-C.V. gases normally produced are at present burned by flameless combustion in preheated brick chambers, but they form a very suitable fuel for power generation in gas turbines. At this stage there are no projects for using the gas for chemical synthesis. As one of our contributors mentions on a later page, this has been discussed in Russian "popular-science" accounts of their work but it apparently forms part of longer term plans. The gases may be used for ammonia synthesis. Possibly the main technical gains from this visit were lessons in directed drilling including obtaining designs of equipment for drilling vertically from the surface and turning at right angles into a horizontal seam.

Town Waste into Wealth

WE are all so busy turning wealth into waste that it is encouraging to find an example of the reverse process. Bangkok, the capital of Thailand, is to have the largest mechanised composting plant ever built. The plant will be used for turning all the refuse collected from the city's million population into fertiliser in the form of a clean, granulated and sterile material. It is claimed that with this plant Bangkok will lead other large cities in the world in the method of disposing of garbage and incidentally economise in imports of fertilisers. This mechanised method is so hygienic and free from nuisance that houses and schools can be built alongside it. It will receive 1,100 cubic metres of refuse daily. Materials unsuitable for inclusion in compost will be removed by magnetic and manual sorting. The remainder will be shredded

mechanically and separated from non-ferrous metal, ceramics and so on before sewage sludge is mixed with it. The mix will then be subjected to aerobic fermentation under conditions which will kill harmful organisms. After removal from the composting house the compost is to be transported to maturing areas and after six to eight weeks is said to have "a balanced nitrogen/carbon ratio". The yield of the plant—which is to be constructed by John Thompson Ltd. of Wolverhampton—will be some 80,000 tons annually.

In announcing this development, the constructors naturally press the suggestion that other authorities should follow this example and treat their rubbish as a valuable material, not merely as a nuisance. This is an attractive theme, but it should be noted that at Bangkok almost half of the refuse is vegetable or organic waste and therefore particularly suitable for composting. Tins, metal, rubber, glass and ceramics form only about 5%. The proportion of the latter is likely to be much higher in a modern industrial city.

Beneficiation of Peas

PERHAPS it might be described as a special case of ash reduction but it still sounds rather strange to learn that peas can now be effectively cleaned of up to 95% of objectionable foreign material by froth flotation. The flotation cleaner is installed in a pea line between the standard pea washer and the blancher. A normal type of flotation process is used employing an oil in water emulsion and a foaming agent forming froth which selectively floats nightshade berries, weed seeds, thistles and the like from the peas. Apparently the floation cleaner has also successfully been used for the cleaning of Lima beans by separation of pods or heavy material. The small residue of refuse is hand picked from the vegetables.

"Food Technology in Australia", 1957, Vol. 9, No. 11, p. 599.

Echoes of Windscale: The Fleck Reports

OF all the points made in the reports of the two Fleck committees on atomic energy, none is more disturbing than the reference to an acute shortage of expert health and safety staff. So seriously did the relevant committee view this problem that they went outside their strict terms of reference to discuss means of meeting the urgent need to increase the supply of specialists required. The uses of atomic energy are becoming more widespread. Contact with apparatus using it has gone far beyond the ranks of scientific and technical experts. In many senses public safety is now involved. The Fleck Health and Safety Committee endorsed the decision of the Atomic Energy Authority to establish a committee responsible for overall supervision on matters of health and safety and recommended that the Authority should take the lead in building up a supply of the safety staff. Yet there will remain an important role for uncommitted non-official bodies such as university departments and the Medical Research Council working in friendly relations with the Authority but accepting no assurances from them. There will alway be some latent suggestion that a government dominated body such as the Authority might be under political pressure to play down a particular hazard.

The report on organisation draws attention to the varied commitments of the industrial group and its remarkable success in carrying the load. Their conclusion is that continuous pressure to take on new tasks has strained resources to the utmost. The primary task recommended is to ensure that plant is safely and efficiently operated; this means that a greater number of senior technical staff should be used on operations. The advancement of new techniques is of the greatest national importance but the committee observe that this is necessarily subsidiary to the foregoing.

Defibering: A fresh field for ultrasonics

HIGH grade paper pulp can be rapidly produced by using utrasonics to break down cellulose continuously and completely to the single fibre in a hundredth of the time previously required. The process, developed by Prof. P. Willems of the Physico-Chemical Research Institute of Lucerne, is said to be based on the principle of "the kinematic generation of high-frequency effect complexes" which, within less than one second, bring about the disintegration of the continuously processed material into millions of particles. Each milligram particle is exposed for a period of only 0.36 seconds to 853,200 impulses corresponding to an ultrasonic frequency of 2,370,000 c.p.s. It is evident that other fibrous materials should be susceptible to this type of treatment. Licencees for the British Commonwealth are Messrs. George Scott & Sons.

Brimstone

A HOTBED of information is the special number of Sulphur* which opens with a discussion of turbulent layer roasting and ends with an article on converting pyrites roasters to burn sulphur. The machinations of Lucifer are less evident in the intervening contributions. Sulphur is of course itself a devil when contaminating other materials and this valuable little review describes processes for recovering the element from flue gas by dry and wet methods in West Germany. Complementary to these studies is a recent forecast for sulphur by "chemical economist" David Gaber. This resulted from a request by the Cyprus Mines Corporation for advice on trends, addressed to the Stanford Research Institute who have published the findings in their journal (No. 4, 1957). The U.S.A. and Europe account for three-quarters of the world's sulphur consumption. Total demand in 1965 in U.S.A. is estimated at 8.9 million metric tons—an increase of 60% over that of the previous decade. The West European market is almost identical in size and expected to experience almost the same rate of increase. How these rapidly rising demands will be met is the important other half of Mr. Gaber's detailed study.

* Issued by the British Sulphur Corporation, W.1.

Ballistics of Droplets

A FUNDAMENTAL study of droplets, which may have engineering applications—for example in spray drying—has recently been reported by C. C. Miesse.* In order to allow for the effect of the variation of evaporation rate of a liquid droplet with its Reynolds number on its velocity and diameter variations, the analysis considers the ballistics and evaporation (Frössling's) equations simultaneously. The resultant nonlinear equation yields analytical solutions for discrete values of the viscosity to still air evaporation rate parameter, which permit ready determination of the variation of drop size and relative velocity with time or distance. The results indicate that the constant evaporation rate analysis is valid for large values of the parameter mentioned above, but should be modified for smaller values. Numerous illustrative curves are presented, and the analysis is applied to available experimental data.

The author concludes that the ballistics of a liquid droplet injected into a uniform air stream can be determined analytically for several values of the ballistics parameter, by simultaneous solution of the evaporation and ballistics equations. The effect of the increase in evaporation rate due to relative velocity is that the droplet velocity curve shifts in the direction of the injection velocity, and both the distance travelled and droplet lifetime are reduced. Relative velocity effects produce negligible change in the shape of the velocity curves for low evaporation rates, but cause considerable change in the drop-size curves. Comparison of theoretical velocity and drop-size curves with Ingebo's experimental data indicates the direct applicability of the present analysis.

* Journal of the Franklin Institute. Vol. 264, 1957, No. 5, p. 391.

Water, Water, Everywhere

A LIVELY youngster among the R.A. family is the Water Research Association, born July 1955. At present, more than 70% of the water distributed in Great Britain and Northern Ireland comes from its members. Commercial industries serving water supply are also finding it useful to join. Membership for 1957 is 231 and the estimated income £20,000. In the Dec. 1957 issue of the bulletin "Water Research News", there is an interesting article by the Director, Dr. R. C. Allen, setting the newcomer in perspective among the other cooperative research bodies more than half of which receive financial aid from the Government without seriously losing independence of action. The W.R.A. in due course will have to draw up a five year research programme since they intend to apply for inclusion in the grant-aid scheme which is administered through the Department of Scientific and Industrial Research. The Council have now obtained a site and buildings on the Thames at Medmenham in Buckinghamshire. Here it is planned to construct a pilot plant to treat water from the Thames and so test out fundamental studies on coagulation. There will also be work on sedimentation and filtration.

In Britain today there is increasing concern over future water supplies of the various qualities required for different purposes. Dr. Allen was naturally anxious to show that these research projects could pay dividends to the water industry but in a wider sense we are all beneficiaries and it might be useful for more bodies to become shareholders in this water undertaking.

Throttling Flow Meter with Low Head Loss

WANDERING around that interesting building Dechema Haus during a recent visit to Frankfurt we came across a novel flow measurement device which is claimed to have the lowest pressure loss of any short throttling type meter. This is a double nozzle tube of a new profile. Bopp and Reuther GmbH—the makers—claim that their short venturi tube has hitherto represented the throttling device with the lowest pressure loss taking into account the length. Of course tubes with greater length and therefore a longer diffusor give a further gain in pressure recovery. However, this firm now claim that with the development of their double nozzle tube they have halved the pressure loss of the short venturi tube so that longer venturi tubes have now even further lost their usefulness. The advantage to plants where pressure drop is a serious problem is quite obvious. The reduction in pressure loss is attributed to the unusual throat section giving a higher pressure efficiency. The form and the results claimed appear to be comparable with those for the Dall tube of George Kent Ltd. and it would be interesting to see objective comparisons of the performance of these and other recent low-loss meters.

Fire Hazard in Cutting and Welding

DURING the last 5 years for which figures are available an average of nearly 700 fires a year caused by flame cutting or welding processes have been attended by fire brigades in the United Kingdom. There were undoubtedly many more cases where the brigades were not called. These accidents form the background to a practical simple folder-leaflet issued by the Fire Protection Association on the necessary precautions when using an oxy-acetylene flame or electric arc. Vivid little sketches make this a useful educational tract to put into the hands of all relevant staff. Undoubtedly the chief danger arises where welding or cutting is carried out in improvised conditions rather than in a department devoted to this class of work. Many of the fires caused during cutting and welding are begun by sparks, molten metal or hot electrode stubs falling on to combustible material, or by direct ignition from blowpipes. Other risks arise from faulty or badly maintained fittings, incorrectly connected electric welding equipment or by transmission of heat through material being welded or cut. Most of the measures suggested to prevent mishap appear to be statements of the obvious. Yet the tally of fires indicates that what appears to be self-evident is often overlooked and that a guide to practice fulfils a need. From the many recommendations, two appear to us of especial value. Welders, who should be instructed in fire-fighting, should not be allowed to work alone, and portable fire-extinguishing equipment should be provided near the direct place of work. May we suggest that readers will find it interesting to check at this moment how many of their maintenance and construction welders are working on their plant in accordance with "obvious" precautions.

Recovery of Monomer from Methacrylate Resin Scrap

A SIMPLE process has recently been described by Michel Maret* for recovering monomer from scrap methacrylate resin such as Perspex, Paxiglas, Lucite and so on, by thermal depolymerisation. The scrap is crushed to less than 18 to 25 mm. and passed by means of an Archimedean screw through a horizontal tube electrically heated to between 380°C. and 400°C. The tube—about 2½ metres long—is made of heat-resisting steel and with a slightly oval cross-section, the mean diameter being 30 centimetres. As the scrap travels along the tube it decomposes, the vapour passing along the free channel formed by the oval section to an off-take tube leading to a water cooled condenser. It is claimed that the depolymerisation is practically complete; only a small amount of carbon and of unchanged scrap is discharged as solid. Even these are separated and the scrap re-circulated. The crude monomer condensate is dissolved in concentrated sulphuric acid then the solution diluted with water forming two layers. The methacrylic ester layer is separated, washed with water and finally purified by distillation. Plasticiser in the resin, usually 4 per cent of dibutyl phthalate, does not interfere with the depolymerisation and the final yield of pure monomer compound is reported to be about 80 per cent.

* L'Officiel des Matières Plastiques, Dec. 1957, p. 51

Industrial Heating by Nuclear Power?

NUCLEAR reactors cannot be used simply for supplying central heating for large buildings because the power factor is too low. In the first instance therefore any direct use of reactor heat will be for industrial purposes. In a recent paper to the Institution of Gas Engineers (Publication No. 513), J. V. Dunworth reported that study is proceeding to determine processes that could benefit from the very cheap heat which nuclear power will make possible. Cheapness will depend on having a very large installation that needs the equivalent of a few hundred thousand kilowatts of electrical heat. There would appear to be no reasonable economic possibility at the moment of supplying heat in comparatively small amounts for individual buildings for comfort purposes, or for supplying small quantities of heat for industrial processing. Furthermore, coolant exit temperatures are not likely to exceed 1,000°F in a commercially operating system during the next 10 to 15 years. Dr. Dunworth, who is Head of the Reactor Division of the Research Group, added that a considerable amount of interest is being shown at the present time in building reactors in which the irradiation of materials in the reactor is directly responsible for chemical reactions or physical changes in a solid. For example, tyres have been vulcanised. It is, however, much too early to assess likely developments.

Canadian Customers

IN so far as the objective of the Canadian Trade Mission which visited Britain recently (see *British Chemical Engineering*, 1958, January, p. 3) were to awaken the interest of British producers to the quickly growing potentialities of the Canadian market, and to see for themselves the goods and production capacity in Britain, the visit has been an outstanding success. The Mission have announced in glowing terms their satisfaction with British industry, which, on the whole they say, is showing leadership of a high order in its scientific research, new technologies, and efficiency of its manufacturing processes. They spoke, too, of their particularly favourable impression of the knowledge, ability and leadership of the senior personnel they met from the foreman level upwards, and of the skill, artisanship and productivity of the workers. The price of the products was competitive with that of American equivalents and the quality was generally recognised as being first class. The U.K. industry, however, was at a disadvantage from the point of view of supply by comparison with the United States because of the hard facts of geography and Canadian buying habits. Steps the Mission proposed that would help to overcome these difficulties include those of urging Canadian purchasers to plan their requirements sufficiently far ahead to give British suppliers a fair chance of meeting delivery date requirements; and of analysing more closely official purchases. Reasonably they suggest that British manufacturers should give Canadian orders priority in their manufacturing and stocking schedules. On the British side already industry has responded to the Canadian initiative by arranging to send a strong return mission under the Dollar Exports Council in the spring, and the Government has promised to consider what part they can play in this. During the visit the Dollar Export Council urged strongly that arrangements should be made for the certification for Canadian use of plant such as pressure vessels to be conducted in Britain like the arrangement now working satisfactorily for electrical apparatus. Another useful suggestion—and one that has the support of the President of the Board of Trade—is for the exchange of students and apprentices between Canada and Great Britain.

Canada's needs are primarily for capital products and apart from the possibilities of extending the sales of British-made petroleum equipment to Canada, which have been discussed in these columns several times recently, the Dominion's petrochemical industry must certainly be a potential ground for expanding British trade. According to the recently published report of the Royal Commission on Canada's economic prospects in the chemical industry, production of petro-chemicals has increased about fivefold, since 1947 (from $24 million to $127 million). In the Commission's opinion, petrochemicals production forms the "growing layer" of the Canadian heavy-chemicals tree.

Special Courses in the London Area

SCATTERED information is usefully drawn together in the current Bulletin of Special Courses in Higher Technology for London and the home counties region. The present issue lists courses running in the Spring and Summer Terms 1958. Some are on subjects which one would have scarcely thought amenable to systematic teaching. "Interviewing Techniques" for example rates a series of thirteen lectures treating the subject in relation to employment policy, or for the purpose of obtaining and giving information, and interviewing in connection with promoting high morale. On a more prosaic level are several courses on mathematics for engineers and on statistical techniques. Fluid flow, gas chromatography, heat transfer and materials in nuclear energy are also among the many other subjects receiving special attention in the region. The bulletin quotes only advanced courses which do not regularly appear in college calendars as part of a grouped course and excludes courses leading to higher qualifications. It costs 3s. and is obtainable from the Regional Advisory Council for Higher Technological Education, W.C.1.

Sir Alexander Fleck Picks out Highlights of 1957

ON his installation as President of the British Association, Sir Alexander Fleck took the occasion to note some of the more active aspects of science in 1957. Chemical engineering as such received no mention but some of the chemical advances cited are relevant to our interests. Boron hydrides, which with fluorine fulfil the requirements of a rocket fuel, are gaining in importance. Production of these and of synthetic diamonds has markedly advanced in 1957. The latter process uses pressure of over a million pounds per square inch with temperatures of the order of 3000°C. In biochemistry a British team has shown the production of spectacular increases in the height and weight of several plants such as wheat by the action of the plant growth-promoting substances gibberellic acid and related compounds. Will these substances in time become as practically important as fertilisers and eventually enter into large-scale production?

An apparently more domestic highlight of the B.A. was the decision to set up a panel of speakers. Its essential characteristic is that members should be able to put across science to general audiences and to young people. This was one of the features of Sir Alexander's speech which received some notice from the general press. With the announcement came an invitation. "The gift of interpretation is not given in equal measure to all of us, but to those who have it in good measure, I appeal to join the panel and to play a part in the interpretation of new discoveries."

"I WAS THE VILLAIN"

—HOT WATER PIPE HISSES

"I work in a block of flats. It is my job to carry hot water up to baths and radiators. But they might have called me Luke for all the warmth I used to deliver! I lost most of it on the way! First there was Fred, the boilerman, he used to warm his feet on me; then Mrs. Fred the housekeeper, used to drape her smalls over me. And so I cooled as I climbed. But now that's all changed. I'm decently dressed and decently behaved. Rigid sections of Fibreglass hold me tight—from boiler to tap. Now it's hot radiators and boiling baths for everyone, everywhere. All my own work—with Fibreglass of course!"

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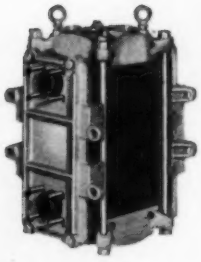
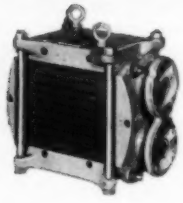
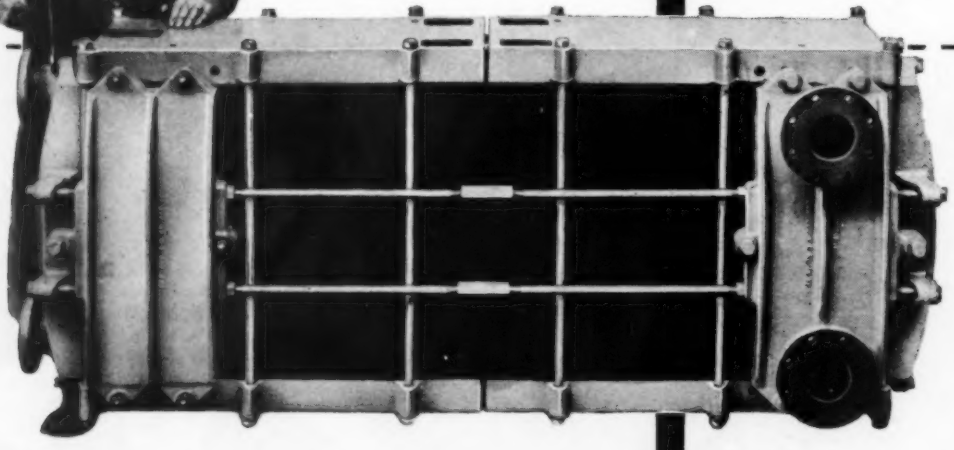


NEW GRAPHITE BLOCK HEAT EXCHANGERS

New models now provide heat surface areas from 4 sq ft to 200 sq ft



- Twenty models are now available to extend the range of graphite block heat exchangers to suit all corrosive industrial duties.
- All models are suitable for use as heaters, coolers, condensers, or evaporators, involving one or two corrosive fluids and employing single- or multi-pass flow for either fluid.
- All units are designed to provide the accepted graphite block advantages of robustness, compactness, ease of installation and maintenance.
- Tube (hole) dimensions of $\frac{3}{8}$" or $\frac{1}{4}$" or rectangular slots are available to suit heat transfer requirements or industrial scale problems.



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A HEYWOOD PUBLICATION
British Chemical Engineering

Low-temperature Conference

MANY of the materials we use as a matter of course in our everyday lives, including such diverse materials as steel at the one extreme and polyethylene at the other, depend for their existence upon gases of some degree of purity. Since the many industrial and those gases found in nature occur as mixtures, they require a process of separation into pure components if the best and most economic results are to be derived from them. Of the available processes, including those based upon chemical combination, absorption and adsorption, thermal diffusion and low-temperature liquefaction, the last-mentioned is by far the most important. It is a reflection upon the status of low-temperature methods that every new steel works in Britain has its own large-scale, low-temperature air separation plant for supplying oxygen to the steel-making processes and that the older plants are making greater use of oxygen. Apart from steel, the synthesis of ammonia, the manufacture of acetylene from methane, the extraction of olefins from refinery gases and the gasification of brown coal are but a few of the other important industrial processes which rely upon low-temperature methods. So far have the techniques advanced, that in the case of tonnage oxygen the product can be counted as the cheapest high-purity chemical available to industry today.

We should remember that in common with many other branches of applied science, gas liquefaction and separation have not followed a path in history undisturbed by failure and disappointment. At times it has seemed that conceptions have arisen which have hindered its progress; such as the idea of permanent gases which remained in currency until Dalton's time. It is much to his credit that he dismissed the possibility of non-liquefiable gases and, moreover, outlined one of the methods by which many gases could be liquefied. After this there followed the relatively easy successes of Faraday, who, by combining cooling and pressure, liquefied such gases as chlorine, and the fruitless efforts of Natterer to liquefy air by pressure alone. This setback, inexplicable at the time, led to a temporary resuscitation of the theory of permanent gases. It was left to Andrews in 1863 to dispose finally of this concept with his discovery of the critical temperature, but this important finding was confined to CO_2. Twenty years were to pass before Cailletet was to succeed in producing a fine mist of oxygen; a few years before this event Joule and Thomson had observed the cooling effect produced by throttle expansion gases, an effect which Cailletet combined with precooling and pressure. Pictet improved still further upon Cailletet's technique of precooling by introducing a system of temperature falls (cascades) employing CO_2 and SO_2, a method still further improved by Wroblewski and Olzewski. They added an ethylene stage and, as a result, were able to produce appreciable quantities of liquid oxygen.

During the period when the methods of producing cold were being steadily developed, Claude was among those who became interested in the possibility of distilling liquid air into its two main constituents, but the honour of producing a small-scale plant for this purpose fell to Linde (1902); his method, however, had the disadvantage of rejecting one-third of the oxygen in the air feed. The persistent Claude, despite many more setbacks, improved upon Linde's original method by using an oxygen-enriched liquid-air feed as well as nitrogen reflux. Shortly afterwards Linde followed with the well-known double column; thereafter, mainly through the work of the Linde Company, the manufacture of oxygen and nitrogen increased steadily, accompanied by detailed improvements in design. The introduction by Fränkl of the regenerator (1928) paved the way for the large-scale Linde-Fränkl oxygen plants—the forerunners of the modern tonnage oxygen plants.

Although the history of low-temperature gas separation had been largely the history of liquid air and its fractionation, how broad the field of application has become was demonstrated by the scope of the recent Conference on Low-temperature Techniques. One paper was devoted to methods of purifying hydrogen as a step in the separation of deuterium from hydrogen by fractionation—a process requiring a temperature of 20°K. This shows how the limit of low-temperature processes is being shifted many degrees lower, in fact, to the temperature of liquid hydrogen.

We listened to an account of the use of digital computers for carrying out distillation calculations and to an outline of their influence upon the economics of design. Many present were no doubt relieved to learn, in the face of the apparent complication of computers, that the coding could be carried out by "programmers" of draughtsman level. So valuable had the computer proved in this particular case that it was now used for all design work.

Ammonia synthesis from refinery gases and the recovery of olefins and hydrocarbons were among the other subjects dealt with at the Conference while the problem of full utilisation of large-scale oxygen plants was dealt with in two noteworthy papers. In these two quite different approaches were made according to the different circumstances of manufacture. One approach, represented by the Rescol Process (see page 91) with its balanced output of gas and liquid oxygen, must rank as a very elegant process and a first-class chemical engineering achievement.

This Conference served to emphasise the present-day scope of low temperature processes. As such, the Conference organisers, the Low Temperature Group of The Physical Society and the Institution of Chemical Engineers, are to be congratulated for sponsoring what must be considered as one of the outstanding international events in the chemical engineering world of 1957.

STUDIES IN MASS TRANSFER - PART I

by N. J. HASSETT*
B.Sc., Ph.D., M.I.Chem.E.

In this article, the author takes a new look at mass-transfer operations and deals with the approach towards equilibrium and theoretical and operating transfer stages

MASS-TRANSFER systems are designed on the basis of equilibrium data, and in evaluating a continuous process it is an accepted method to derive a number of theoretical transfer stages using this data, thereafter making allowance for operating stage inefficiency. This inherently assumes that all the constituents in the system approach equilibrium at equivalent rates. In point of fact, however, in cases where molecular diffusion plays an appreciable part as compared with convection or bulk transfer, each individual constituent in a system approaches equilibrium primarily with its own particular rate factor and is only secondarily concerned with the other constituents. In a mass-transfer process, a phase enters a transfer stage very much out-of-balance, and leaves the stage more closely in equilibrium with, but still not quite in equilibrium with the other phase in that stage. During the contact period, the different constituents will have progressed different distances on their individual paths towards equilibrium. In cases of mass transfer other than those concerning binary systems, therefore, the conventional method of stage-to-stage calculation may lead to an accumulative incorrect constituent distribution. The same considerations apply to evaluation of the transient response of multi-component mass-transfer systems.

Mass transfer is concerned with the transfer of disperse matter, usually molecules, within a system which may be simple or complex. The simple system is a single, uninterrupted phase wherein mass transfer may be by virtue of movement along concentration or composition gradients and also by convection. A complex system can either be multi-phase or an interrupted single phase, such as a gas or liquid divided by a permeable membrane boundary or porous solid.

A fundamental principle in mass-transfer theory is that a bounded phase tends to a homogeneous or uniform composition within itself in accordance with a probability distribution law. Deviations due to temperature gradients, component density differences or other causes, which in some cases have useful application, are not significant in the more common mass-transfer operations such as distillation and extraction where turbulence is present. A second fundamental principle relates to multi-phase systems. Under fixed conditions of temperature and pressure, a system of given components tends to an equilibrium with the constituents partitioned between the phases in a unique manner dependent only upon the relative proportions and characteristics of the constituents and not on any initial distribution between the phases.

* *Senior Lecturer, Loughborough College of Advanced Technology.*

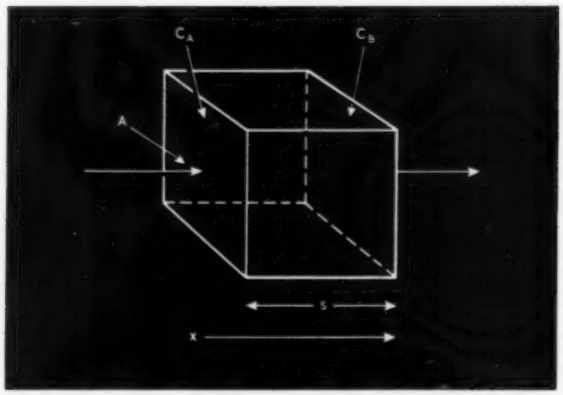


Fig. 1. The process of mass transfer in an elementary cube in a unidirectional concentration gradient.

In complex systems, mass transfer can be considered to have composite efficiencies or rate factors. The first of these is defined by the rates of movement of the constituents within each phase or separately bounded part of the system, tending to bring it to uniform composition, or phase internal equilibrium. This again is composite, since it embraces both diffusion and convection. The second is defined by the rates of transfer of constituents across what may be considered the boundary between the phases or defined parts of the system, leading towards interphase equilibrium.

The rate of attainment of interphase equilibrium is directly proportional to the boundary area between phases, whilst that of phase internal equilibrium is inversely proportional to the distance molecules must travel to get to a boundary. For these reasons, fine dispersion and intimate mixing of phases speed up the equilibrium process.

In a mass-transfer operation where phases are brought into contact and separated, there are then three stage efficiencies to be considered—quite distinct in character:

(a) phase internal equilibrium efficiency;
(b) interphase exchange efficiency; and
(c) phase separation efficiency (in stagewise operation); or distribution efficiency (differential operation)—occasionally occurring together.

For example, in a plate rectification column, bubbles of gas rise through the liquid on a plate. There is an initial interchange at the surfaces of the bubbles which results in a composition gradient inside each bubble and also in the liquid immediately adjacent to the bubbles. In the short

interval before the bubbles emerge, molecules travel along the composition gradients in both gas and liquid, enabling continued exchange at the interface. Convection or eddy currents within the bubbles as well as in the continuous phases combine with molecular diffusion to this end.

A similar movement and transfer of matter takes place in the vapour space where droplets of liquid exchange matter with the continuous vapour phase. The overall mass-transfer efficiency is a function of the efficiencies of these transfer operations, coupled with a separation efficiency (cf., entrainment).

The Driving Force in Mass Transfer

The very nature of a mass-transfer process indicates that it operates under non-equilibrium conditions, and the driving force is the "out-of-balance". Within a phase, the out-of-balance takes the form of concentration gradients. Between phases, the out-of-balance can usually be considered as a step difference in normalised concentration. Normalised concentration is a conception that is sometimes useful in working out certain types of mass-transfer problem. Thus, if the partition coefficient of a given constituent between two phases with respective volumes V_A

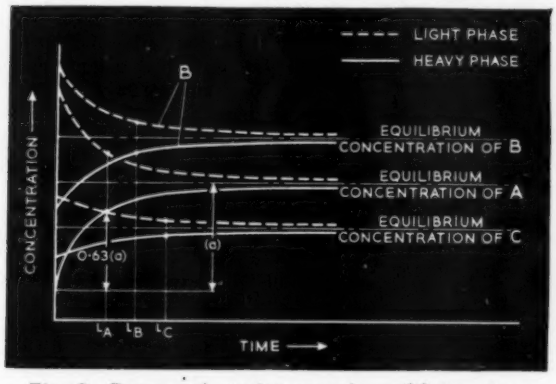


Fig. 2. Degree of attainment of equilibrium in a three-component system.

and V_B is 3, and the concentration in each phase 0.1 and 0.15, the normalised concentrations and volumes would be 0.1; V_A, and 0.45; $V_B/3$ respectively for the two phases, taking the first as standard. Alternatively, they could be 0.033; $3V_A$ and 0.15; V_B, taking the second phase as standard. The term normalised concentration will be used in this text in that sense, and will therefore indicate the driving force directly.

Mass-transfer processes broadly fall into one of two categories. In the one, the out-of-balances or driving forces throughout the system remain constant, and the process operates under steady-state conditions. An example is a continuously operating rectifying column. Such conditions are often referred to as equilibrium conditions, but the term is evidently loosely employed in that connection and is misleading.

The second mode of operation is where the process is bounded and the approach to equilibrium is a transient one; in other words, the out-of-balances are continuously diminishing at all points and the whole is tending to come to equilibrium *in situ*. This is termed batchwise operation. Transient operation also arises in the starting-up or shutting-down of continuous mass-transfer processes.

Fundamental Considerations

The mathematical treatment of a mass-transfer process must be ruthlessly simplified if it is to become at all workable and useful. This will be seen by considering the elementary case of a single constituent moving along a unidirectional concentration gradient in a fluid phase by molecular diffusion. Its molecules will be moving in random directions, but there will be a net movement along the concentration gradient. An elemental cube of side s in such a gradient is shown in Fig. 1 with side A normal to and facing the gradient rise, so that there is a net input of molecules into the cube through that face given by:

$$dq_A/dt = s^2.(D/R_A)\,dc_A/dx \qquad \ldots.(i)$$

where D = diffusivity of the constituent defined as the net transfer across unit area normal to flow direction per unit concentration gradient, per unit resistance of the medium;

R_A = the resistance of the medium in units defined by the preceding definition of D; and

dc_A/dx = the concentration gradient at A.

In like manner, there will be a net output of molecules through the opposite face given by:

$$dq_B/dt = s^2.(D/R_B)\,dc_B/dx \qquad \ldots.(ii)$$

There will be no net transfer across any other face of the cube, since they all lie parallel to the concentration gradient.

Now D is a function of the molecular weight of the constituent and temperature and could be an invariable, but R is a function of the composition as well as temperature and pressure, and since the composition must necessarily change as mass transfer proceeds, it is unlikely to be invariant.

However, considering R as a constant, there will be a net gain of molecules in the cube given by (i) − (ii), leading to a concentration change of

$$dc/dt = [\,(i) - (ii)\,]/s^3 \qquad \ldots.(iii)$$

The concentration gradients dc_A/dx and dc_B/dx can be put in terms of the average concentration c within the cube thus:

$$dc_A/dx = dc/dx - (s/2)\,(d^2c/dx^2) \text{ and}$$
$$dc_B/dx = dc/dx + (s/2)\,(d^2c/dx^2)$$

Resolving these equations leads to the basic equation for this type of mass transfer:

$$\frac{dc}{dt} = -\frac{(D)}{R}\left(\frac{d^2c}{dx^2}\right) \qquad \ldots.(1)$$

This innocent expression is identical in form with that for unidirectional unsteady heat transfer and its integration is given in Coulson[3] (pp. 158-60). Inspection of the solution indicates that to obtain workable solutions for the very much more complex conditions encountered in practice requires a different approach.

The case of steady-state mass transfer demands that (i) is equal to (ii), since there must be no accumulation or depletion at any point in the system, but this does little to lighten the complexity of a rigorous mathematical treatment of such systems.

In a confined system which is approaching equilibrium, the rate of approach is proportional to its decreasing out-of-balance or concentration gradients, so that equilibrium is attained in an approximately exponential manner, much as a process stage approaches equilibrium following a step disturbance. The definition of out-of-balance will depend upon the particular system under consideration and a precise evaluation of the degree of out-of-balance may not be possible in a heterogeneous system. The following example illustrates this particular point and indicates a possible approximate approach.

Consider a layer of 6 in. of water over an equal layer of 5% salt solution with complete absence of any convection currents. There will be a diffusion of salt into the upper layer, tending towards an overall concentration of 2.5%. Initially, there will be a relatively fast transfer at

the interface which will slow down as the concentration gradient becomes more diffuse. The driving force at any point is the concentration gradient, and it is evident that, during the earlier stages at least, there would be considerable difficulty in evaluating an average concentration gradient, or the approach to equilibrium. If, however, the two layers were separated by a porous membrane and each layer constantly vigorously stirred, the driving force towards equilibrium would be the step difference in concentration, and the resistance would be located at the porous membrane and would be considered constant.

At any moment, the rate of transfer of salt from the lower to the upper layer can be expressed as

$$dq/dt = (c - c')/R$$

$$\text{or} \quad -dc/dt = (c - c_E)/R' \qquad \ldots.(2)$$

where c and c' are the concentrations of lower and upper layers respectively and R and R' are defined by the equations. c_E is the equilibrium concentration $= \frac{1}{2}(c + c')$.

Integrating Equation (2) from zero time when $c = c_o$:

$$ln\left(\frac{c-c_E}{c_o-c_E}\right) = -\frac{t}{R'} \qquad \ldots.(3)$$

whence $$c = c_E + (c_o - c_E)e^{-t/R'} \qquad \ldots.(4)$$

Similarly $$c' = c_E - (c_E - c_o')e^{-t/R'} \qquad \ldots.(4a)$$

The out-of-balance is readily defined as $(c - c_E)$ which is seen to be equal to $(c_o - c_E)e^{-t/R'}$, and therefore to diminish exponentially with time.

As a very rough approximation or simplification, the case of diffusion without the membrane could be treated similarly, c and c' being the concentrations at the bottom and surface layers respectively. The same equation would derive, but with a different constant term instead of R'. This term defines the speed of approach to equilibrium and will be denoted by L, the time constant or rate factor of the process. It will be noted from the form of the equation that L must be in units of time. The out-of-balance at any moment could be defined as the overall or maximum concentration difference $(c - c')$, which is also the overall driving force, but this would depend upon the particular system under consideration.

The application of this approach is shown by the following example.

EXAMPLE 1. ESTIMATION OF TIME CONSTANT

Fifty grammes of prepared oilseed containing 15% by weight of oil are leached with 100 grammes of solvent containing 1% of oil under conditions simulating batch process extraction. A sample of miscella contained 7% of oil after 10 minutes. What is the time constant of the extraction process and when would the oil content of the miscella reach (a) 7.5%, (b) 7.8%, and (c) what will be the composition of the miscella after 30 minutes?

Answer: The equilibrium concentration c_E is first found by compounding the total quantities of oil and solvent in the system.

Oil in oilseed $= 50 \times 0.15 = 7.5$ g.

" " solvent $= 100 \times 0.01 = 1.0$ g.

Equilibrium concentration $c_E = \left(\frac{7.5 + 1}{100 + 7.5}\right) = 7.9\%$.

Determination of time-constant (cf. Equation 4):

$c'_o = 1\%$, $\quad c'$ at $t = 10$ min $= 7\%$.

$c_E = 7.9\%$,

$c' = c_E - (c_E - c'_o)e^{-t/L} \qquad \ldots.(5a)$

$7 = 7.9 - 6.9e^{-10/L}$,

whence $L = 5$ min.

(a) Using Equation (5a)

$$7.5 = 7.9 - 6.9e^{-t/5}$$

whence $e^{-t/5} = 0.058$, and $t/5 = 2.84$

$t = 14.2$ min.

(b) Similarly,

$$7.8 = 7.9 - 6.9e^{-t/5}$$

$e^{-t/5} = 0.0145$: $t/5 = 4.24$

$t = 21.2$ min.

(c) Again from Equation (5a)

$$c' = 7.9 - 6.9e^{-30/5}$$

$$= 7.9 - 6.9 \times 0.0025$$

$$= 7.883\%.$$

Operating conditions will usually depart from a pure exponential response, as well as having the complicating factors already mentioned, but this treatment gives a reasonable guide to scale-up.

Component Rate Factors

Mass transfer within a phase will usually be by virtue of both molecular and eddy or convection transfer. In the first case, the rate factors of the different constituents in the phase will usually all be different, since the diffusivity is a particular function of a given molecule. On the other hand, the eddy or convection rate factors are functions only of the velocity and distribution of the convection currents and will be the same for each constituent. From this, it follows that equilibrium in a multi-component phase will be approached by the various constituents at very different rates if molecular transfer predominates, but less so as convection transfer plays a more important part until the case where convection predominates, when equilibrium within a phase is approached along proportional paths by all the constituents.

In the general case, and probably always where interphase transfer is also concerned, each component will have its own rate factor which can only be determined experimentally, except in cases where molecular diffusion predominates. Even in the latter case, it will be necessary to determine one key rate factor experimentally.

The rate of approach to equilibrium of any component is then defined by its time-constant or rate factor L, which is the time taken to attain 63% of its way to equilibrium, irrespective of the starting concentration c_o.

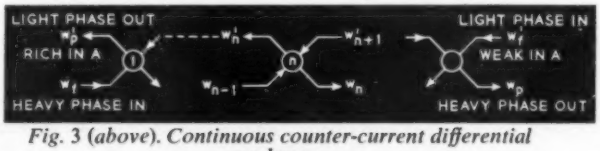
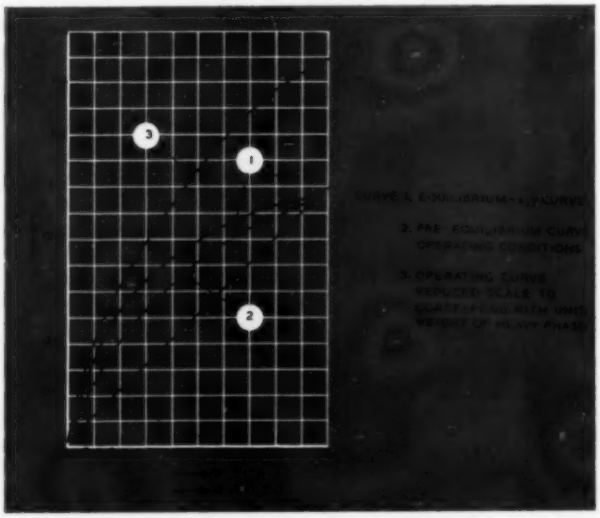


Fig. 3 (above). Continuous counter-current differential exchange.

Fig. 4. Preliminary steps in estimating graphically the number of stages—equilibrium and operating curves.



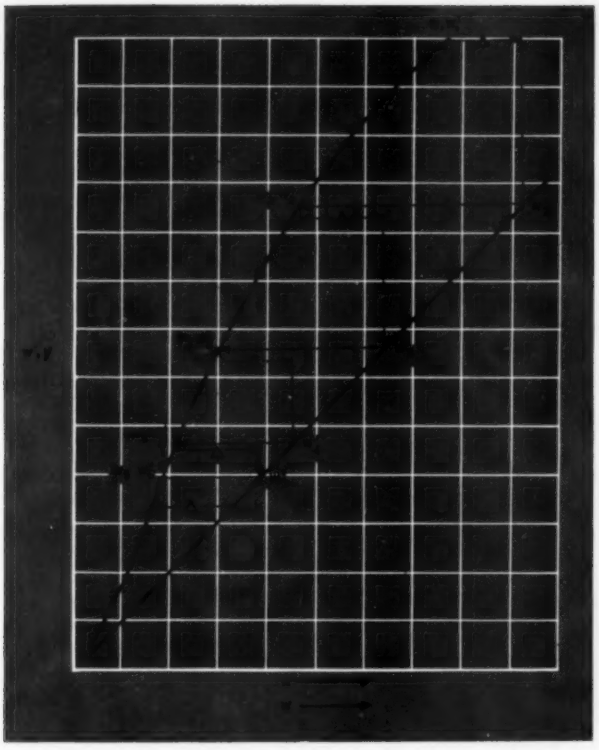


Fig. 5. Graphical determination of the number of actual stages in a mass-transfer exchange process.

Then the concentration at time t is given by either Equation (3) or (4) with L substituted for R', as in Equation (5a). Using the corresponding equation for c:

$$c = c_E + (c_o - c_E)e^{-t/L} \quad \ldots . (5)$$

The distance traversed towards equilibrium at time t is then:

$$(c_o - c) = (c_o - c_E) - (c_o - c_E)e^{-t/L}$$

$$\text{i.e.,} \left(\frac{c_o - c}{c_o - c_E}\right) = 1 - e^{-t/L} \quad \ldots . (6)$$

When $t = L$, this becomes equal to $1 - 1/e = 0.63$ and $(c_o - c)$ is 63% of the original distance to equilibrium $(c_o - c_E)$. In the numerical example just given, the original out-of-balance of the solution or miscella was $(c_o - c_E) = 1 - 7.9 = -6.9\%$.

The concentration after time $t = L = 5$ minutes is given by:

$$c = c_E + (c_o - c_E)e^{-5/5}$$
$$= 7.9 + (-6.9)(1/e)$$
$$= 7.9 - 6.9/2.72 = 5.37\%$$
$$c_o - c = 1 - 5.37 = -4.37\%$$

$$(c_o - c)/(c_o - c_E) = \frac{-4.37}{-6.9} \simeq 0.63.$$

Thus in a time period equal to the time constant, the system has moved 63% of the way towards equilibrium. It will be noted that either Equation (5) or (5a) can be used for either phase, provided due account is taken of signs.

The preceding remarks give an introductory explanation of the meaning of rate factors or time constants as applied to constituents approaching equilibrium in a heterogeneous system, and indicate the experimental method of determining a particular time constant. In addition, it has been made clear that each constituent will have its own time constant which will be a function not only of itself, but of the nature and conditions of the mass-transfer operation.

It follows, therefore, that equilibrium in or between phases will not be approached in a regular proportional manner, and the analysis of a separation process in terms of theoretical stages using a multiplication factor to allow for stage inefficiency is not strictly justifiable other than for binary systems. This will be seen better if an attempt is made to define stage efficiency and degree of equilibrium.

Approach to Equilibrium in a Multi-component System

It is difficult, if not impossible, to define the degree of equilibrium of a multi-component phase or system as such, and hence scale its composition in terms of the equilibrium composition, since, due to the individual components proceeding towards equilibrium at different rates and changing relative rates, there is no common criterion. At any moment prior to attainment of equilibrium, each component will have reached its own absolute degree of equilibrium. The following examples make this clear:

(a) In a binary system, suppose the initial composition of a phase to be 40:60 and the equilibrium composition to be 20:80. What degree of equilibrium has been attained when the phase composition has reached 25:75?

It is useful to consider both the absolute out-of-balance and proportional approach as possible defining means. We then have for the individual components:

	A	B
Equilibrium composition ...	20	80
Initial composition ...	40	60
Final composition ...	25	75
Initial out-of-balance	$40 - 20 = 20$	$60 - 80 = -20$
Final out-of-balance	$25 - 20 = 5$	$75 - 80 = -5$
Initial degree of equilibrium	$40/20 = 200\%$	$60/80 = 75\%$
Final degree of equilibrium	$25/20 = 125\%$	$75/80 = 94\%$

(b) In a ternary system, suppose the initial composition of a phase to be 10:20:70 while the equilibrium composition is 20:25:55. What degree of equilibrium has been attained when the composition has reached 16:22:62?

Tabulating as before.	A	B	C
Equilibrium composition	20	25	55
Initial composition	10	20	70
Final composition	16	22	62
Initial out-of-balance	−10	−5	+15
Final out-of-balance	−4	−3	+7
Initial degree of equilibrium ...	50%	80%	127%
Final degree of equilibrium ...	80%	88%	113%

Inspection shows that using the criterion of out-of-balance, each component in the binary system has progressed three-quarters the way to equilibrium compared with its original condition. Both components are, incidentally, necessarily always out-of-balance to the same absolute measure, so that it would be possible to derive a definition for approach to equilibrium attained by a binary system which would also define that of each component. In the case of the multi-component system, this would not be possible. The figures in the table show the absence of any general correlation. Any attempt to define the degree of equilibrium or approach to equilibrium of a multi-component phase or system, whether on an absolute, relative or proportional basis, can only be arbitrary.

Fig. 2 illustrates the foregoing argument and shows how the three components A, B, and C, whose molecular weights increase in that order, could redistribute between two phases. The concentrations have been normalised to

simplify the diagram, and the time-constants of the three components are indicated by L_A, L_B and L_C respectively. Fig. 2 also illustrates that equilibrium is only reached in infinite time, and that the mode of approach can lead to useful industrial applications.

Continuous Mass Transfer Operations

Counter-current continuous mass transfer between two phases can be effected by contacting the phases in continuous stream (continuous counter-current differential exchange) or in a series of stages (continuous counter-current stage exchange). Other modes will not be discussed, since the points to be raised are fundamental and their general application follows from the application to the modes now described. One method is illustrated in Fig. 3 and with reference to any chosen component A. The method illustrated can be defined in terms of transfer stages.

A theoretical transfer stage is one in which the leaving phases are in equilibrium. Since equilibrium is only attainable in infinite time, a theoretical stage must have infinite capacity for any throughput above zero, or zero throughput for finite capacity. Mass balances can, however, be readily made around a theoretical stage of infinite capacity, because, as we are concerned only with input and output, the inventory will remain constant.

The accepted method of design is to ascertain the number of theoretical transfer stages required for a given separation and multiply by an inefficiency factor. The inefficiency or safety factor is a useful device for covering the inadequacy of methods of evaluation in general, and is an essential concomitant of technological application. However, used as it is in mass-transfer calculations, it can lead to a wrong conclusion regarding the distribution of components in multi-component systems. The preceding remarks indicate that since the individual components in a phase approach equilibrium differently, and operating stages will never be at equilibrium, it will be possible to design only for one component. Having designed for that component, however, it will be possible to evaluate for the other components on the basis of their relative time-constants.

If the total mass throughput per unit time is $\dot{m}$ and the inventory of a stage is M, the residence time of the material which actually follows an exponential pattern can, as a first approximation, be considered to have an average value of $\dot{m}/M$. This can be related to the time-constants of the partitioning components as derived theoretically or determined experimentally.

As an example, suppose the problem relates to the extraction of the two substances A and B, whose time-constants, as determined experimentally under conditions approximating to those anticipated for the full-scale plant, are found to be 10 and 16 minutes respectively. Then for a stagewise process and a throughput rate of, say, 200 gph, a stage of capacity 50 gal, would give an average residence time of 15 minutes. The approach towards equilibrium of each component is given by (cf. Equation (6)):

$$[E]_A = 1-e^{-t/L} = 1-e^{-15/10} \simeq 0.78 \text{ (i.e., } 78\%)$$

$$[E]_B = 1-e^{-15/16} \simeq 0.60 \text{ (i.e., } 60\%)$$

This treatment, although essentially simplified, gives a lead to methods of designing the size of mass-transfer equipment in relation to stage efficiency. It also shows that a number of operating stages is not likely to give the same result as the same or any other number of theoretical stages.

An alternative approach is to consider stage efficiency prior to evaluating the number of stages. Stage efficiency or degree of approach to equilibrium is largely a matter of contact time and area, and is a factor than can only satisfactorily be determined experimentally, and, of course, each component will have its own stage efficiency.

As an alternative to experimental determination of such data, a pre-estimate can be made on the basis of equilibrium data and molecular weights. Thus if a design is to be based on a 70% equilibrium efficiency for a key component A with molecular weight 80, the equilibrium efficiency for a constituent B with molecular weight 320 would be derived as follows, in a case where diffusion rate is determinant, taking the diffusivity to be proportional to the square root of molecular weight. As before:

$$[E]_A = 1 - e^{-\tau/L_A} = 0.7 \quad \ldots\ldots \text{(i)}$$

$$[E]_B = 1 - e^{-\tau/L_B} \quad \ldots\ldots \text{(ii)}$$

where $[E]_A$ = the approach to equilibrium;

τ = residence time in the stage;

L_A = rate factor of A = constant $\times$ $80^{\frac{1}{2}} = K.80^{\frac{1}{2}}$;

and

$$L_B = \text{rate factor of } B = K.320^{\frac{1}{2}} = L_A \frac{320^{\frac{1}{2}}}{80^{\frac{1}{2}}} = 2\ L_A.$$

from (i) $e^{-\tau/L_A} = 0.3$

and $e^{-\tau/L_B} = e^{-\tau/2L_A} = (e^{-\tau/L_A})^{\frac{1}{2}}$

$= 0.3^{\frac{1}{2}} = 0.55$

and from (ii) $[E]_B = 1-0.55 = 0.44$, i.e., 44%.

Having then determined the number of operating stages for the required separation of the key component A, as shown later, the concomitant degree of separation of the other components can be evaluated in this manner.

The preliminary design is then concerned with equilibrium efficiency of the key component and resolves to the problem of providing sufficient residence time and contact surface for each stage to operate at the design efficiency. In this, cost factors will play a determinant role.

In the continuous counter-current differential exchange system, contact is maintained between the phases throughout the system, and there is an uninterrupted drive towards equilibrium between the phases. If $k.x$ is the potential equilibrium concentration of a component A in the light phase corresponding to a concentration x in the heavy phase, then, denoting location by subscripts and the light phase by a dash, the driving force towards equilibrium at location P is given by $(k.x_P - x'_P)$. If at some point Q, the concentration of A in the light phase, x'_Q, is equal to $k.x_P$, then the light phase at Q is in equilibrium with the heavy phase at P and QP represents a theoretical transfer stage for component A. In that section of the system, a definite net quantity of A is transferred from one phase to the other in unit time. This quantity can be evaluated as shown later.

Since the rate of transfer of A is not only a characteristic of A, but depends upon the composition of the medium, as well as other local conditions, the transfer rate will vary along the system. The length PQ of a theoretical transfer stage will then vary according to the chosen location of P. It also follows from earlier reasoning, that the length of a theoretical transfer stage for component A starting from any given location will not necessarily be the same as that of a theoretical transfer stage for another component, except for binary systems or the limiting case of zero flow rate.

For the case of differential mass transfer, it is then possible to design for any component in terms of theoretical transfer stages since, according to the definition, these can actually exist in the system. A given length of transfer column will, however, be equivalent to a different number of theoretical transfer stages for the different components in the system.

Graphical Method for Number of Transfer Stages

A two-phase separation system can readily be evaluated, one component at a time, irrespective of the total number of components by a quite simple graphical method. The method is of general application and covers theoretical as well as operating transfer stages.

The working data required for the graphical construction are the operating quantities (or relative quantities) of the chosen component in the two phases at a few points in the system, enabling the operating curve to be drawn. The following table illustrates one method of deriving such data.

	Light phase	Heavy phase
Equilibrium data — percentage amounts in (for component *B*) ...	40	30
Actual weights of phases per unit time, say, hour	1000 lb.	500 lb.
Actual weights of *B* in each phase (i.e., *w'* and *w*)	400 lb.	150 lb.
w' and w on unity basis (i.e. ÷ 500)	0.8 lb.	0.2 lb.

The actual weights (or volumes) of the phases can be obtained, for instance, from the chosen reflux ratio or extraction ratio. For operating data, the equilibrium data or the weights can be modified in accordance with the approach to equilibrium expected in the transfer stages. The final figures required are then the $w':w$ ratios of the chosen component instead of the usual concentration relationship. In some cases it will be possible to work directly from an equilibrium curve, and derive the operating curve graphically.

Fig. 4 shows the relation between the equilibrium curve ($x:y$ curve), modified on account of out-of-balance equilibrium curve, and the $w':w$ or operating curve.

Fig. 4 shows how the whole concentration range is covered. In a large number of cases, only a small part of the range will be concerned. Thus, if the problem relates to the extraction of sugar present as a 15% solution in a vegetable matter, the *w* scale would only extend from 0 to 0.2. Where the relative and consequently true absolute weights of the phases change within the system, this must be taken into account and the *w* values related to some fixed standard so that they represent correct quantities passing the relevant location in the system in the time interval chosen. We are concerned with quantities per unit time, and the choice of unit time is a matter of convenience. It is convenient to work in terms of unit quantity of heavy phase, and if the mass or volume flow rate of heavy phase is different in different parts of the system, the time unit is defined for unit quantity of heavy phase either entering or leaving the system, whichever is the more convenient. This will be clear when the worked examples are studied. In the case of leaching, the graphical method is extended to cover this underflow variation.

The number of transfer stages is then determined by simple arithmetic considerations. Since the two countercurrent streams are running under constant continuous conditions, there can be no build up or depletion of any constituent anywhere in the system. Across any cross-section of a differential exchange column or between any two stages of a stage exchange system, the net flow rate and direction of a given component must always have the same value.

Numbering the stages from left to right and denoting the weight quantities of the chosen component in the light and heavy phase by w' and w respectively, we have:
Referring to Fig. 3, net flow rate =

$$\triangle = w'_P - w_F = w'_n - w_{n-1} = w'_{n+1} - w_n = w'_F - w_P$$

This relationship determines the step from the heavy phase in one stage to the light phase in the next stage. The step from the light phase in that stage to the heavy phase in the same stage is given by the $w':w$ relationship. In this manner, it is possible to progress from stage to stage throughout a complete transfer system.

The general method is illustrated in Fig. 5. The value of w'_P which is known from initial data locates the point w_1,w' on the operating line, since w'_P is also w'_1. Adding $\triangle$ to w_1 gives the numerical value of w'_2 which is located by means of the diagonal. This, in turn, locates w_2,w'_2 on the operating curve. In like manner, succeeding stages are reached until the end values are overtaken. The end value in the case shown would be in the neighbourhood of where the horizontal difference line *OD* is indicated on the diagram. This is the operating limit, beyond which no stages can be found.

This simple graphical method can be modified to apply to different types of mass transfer, and will be used to solve problems in distillation, leaching and absorption in a later article.

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ACHEMA JAHRBUCH, 1956-58

THREE KILOGRAMS; four main languages; news of five crowded conferences. Who can supply 7500 items of equipment...? This is almost the yearbook* breathlessly to end all yearbooks, for there is more to add to the tally. Sixty-five reports from research institutions in ten countries, including Britain. A total of 1070 pages. There is a list of trade names and a section entitled "Technical Achievements" which details reports on newer plant and machinery in addition to a more usual advertisement section. Exhibitor members at the Achema Congress in June 1958 are listed and all the information is very thoroughly indexed in four languages, thus forming a technical dictionary. Yet there is mercy too. For one of the fly-leaves acknowledges that the proper place for the Achema Jahrbuch, 1956-58, is on the desk—even during a visit to the Exhibition. Visitors will receive a more modest "Congress Handbook" on arrival in Frankfurt.

This is truly a remarkable reference work reflecting a tremendous upsurge of the German chemical industry and the events it sponsors. Chemical output in Germany has grown roughly twice as fast as in the U.K., although leading economists consider that the disparity in growth rates should be less marked in future. In 1955 German chemicals were a close second to Britain in value of turnover and in men employed. But this book has no British parallel and those connected with the chemical trade would do well to equip themselves with this informative three kilograms. It is being sent free of charge to all who register as visitors to the Achema Congress to be held at Frankfurt (Main), Germany, during June, 1958.

* Achema Jahrbuch, 1956-58. Editor H. Bretschneider, Dechema, Frankfurt (Main), Germany.

FORMATION OF ACETYLENE BY INCOMPLETE COMBUSTION OF METHANE IN OXYGEN

This article describes results obtained in the U.S.S.R. in investigating the process of acetylene formation in a flame. New furnace designs for the manufacture of acetylene from methane are also discussed

by PROF. P. A. TESNER

THE production of acetylene by the incomplete combustion of methane in oxygen has found extensive industrial application in recent years.[1] It is evident that this process is technically and economically the most effective for the production of acetylene from natural gas. However, little has appeared in the literature on the nature of the process.

Thermodynamics of Acetylene Formation

The thermodynamics of the formation of acetylene from methane according to the reaction

$$2CH_4 = C_2H_2 + 3H_2 \quad \ldots . (1)$$

has been studied in detail. Raising the temperature and lowering the pressure shift the reaction towards the formation of acetylene. At 2000°C, thermodynamics allows methane to be practically completely converted into acetylene by this reaction. The resulting gas should then contain 25% C_2H_2 and 75% H_2. However, at this temperature acetylene is thermodynamically unstable with respect to the reaction of decomposition into its elements:

$$C_2H_2 = C_2 + H_2 \quad \ldots . (2)$$

If this reaction is taken into account in the calculation, we find that the production of acetylene at 1000 to 2000°C is practically impossible from a thermodynamic standpoint, because the only stable products at such temperatures are solid carbon and hydrogen. However, unlike all other hydrocarbons, the free energy of formation of acetylene from its elements does not increase with increasing temperature, but diminishes. The result is that, at 2500°C and higher, the gas in equilibrium with the carbon contains a certain amount of acetylene which increases as the temperature rises. Therefore, "thermodynamically stable" (at the temperature of the reaction) acetylene can be obtained at temperatures above 2500°C only.

The formation of acetylene at lower temperatures is possible only because reaction (1) proceeds at a greater rate than reaction (2). Thus the acetylene obtained is a thermodynamically unstable intermediate and can be kept from decomposing only by rapid quenching of the reaction products.

Thermodynamic analysis of the formation of acetylene by incomplete combustion[2] shows that here also the formation of acetylene is thermodynamically impossible. This is due not only to the decomposition of acetylene into carbon and hydrogen according to reaction (2), but also to the acetylene reacting with water vapour and with carbon dioxide to form carbon monoxide and hydrogen, according to the reactions,

$$C_2H_2 + 2H_2O \leftrightharpoons 2CO + 4H_2 \quad \ldots . (3)$$

$$C_2H_2 + 2CO_2 \rightleftharpoons 4CO + H_2 \quad \ldots . (4)$$

As these reactions are shifted completely to the right at temperatures above 1000°C, acetylene cannot be present in the equilibrium gas mixture simultaneously with carbon dioxide or water vapour.

Experiments on the incomplete combustion of methane in oxygen have shown, however, that under certain conditions a considerable amount of acetylene can be obtained together with the carbon dioxide and water vapour. As in the thermal process, the acetylene is again an unstable intermediate and is obtained solely through the rapid quenching of the reaction products.

It is noteworthy that in this case all the rest of the incomplete combustion products are in equilibrium:

$$CO_2 + H_2 \rightleftharpoons CO + H_2O \quad \ldots . (5)$$

This fact, first noticed evidently by Benedek and Laslo,[3] makes thermodynamic calculation of the process possible.[4]

For this calculation five equations are available comprising three equations for the material balance of carbon, oxygen and hydrogen, a thermal balance equation, and the water gas equilibrium equation. These equations have six unknowns, i.e., the five stoichiometric ratios of the reaction products, and their temperature, and it is possible to express any of the five unknowns in terms of temperature. Thus for each methane:oxygen ratio, solution of these equations gives the acetylene yield and the composition of the reaction products.

Fig. 1 presents the results of such a calculation for an unheated methane-oxygen mixture ($O_2:CH_4$ ratio $=0.667$), with temperature of the reaction products as abscissa and the acetylene yield in moles per mole of methane as ordinate. It should be noted that the higher the tempera-

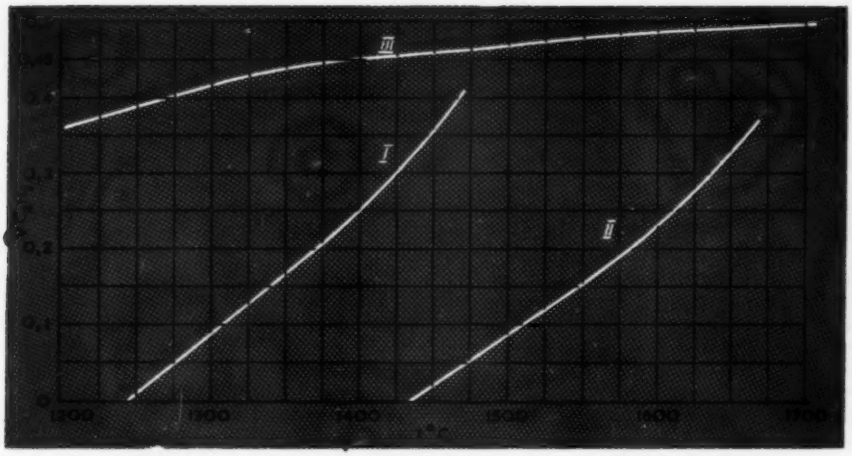

Fig. 1. Dependence acetylene yield (C_2H_2 per mole CH_4) on temperature of reaction products $O_2/CH_4 = 0.667$. Curve 1. Adiabatic without chemical losses. Curve 2. Heat losses 10%. Chemical losses: carbon black 0.03 mole/mole CH_4; methane 0.03 mole/mole CH_4. Curve 3. Thermodynamic maximum yield: $2CH_4 = C_2H_2 + 3H_2$.

ture of the reaction products, the higher the acetylene yield. This seems unlikely at first, because the formation of acetylene requires a considerable expenditure of heat and, therefore, the more acetylene formed, the lower the temperature of the reaction products should be. Actually, this is not so, for although the formation of acetylene does require a considerable expenditure of heat, the latter is more than replenished by the complete combustion of the residual methane.

Another purely thermodynamic explanation of the temperature rise of the reaction products during the formation of acetylene is as follows: as shown above, acetylene is not in equilibrium with the rest of the reaction products. Therefore, if the products formed during the reaction are kept long enough under adiabatic conditions, all the acetylene will change into carbon monoxide and hydrogen owing to conversion reactions with carbon dioxide and water vapour. Since these reactions are endothermic, the temperature of the mixture will drop as the concentration of acetylene falls. The temperature will continue to drop until all the acetylene is used up and a state of equilibrium is reached. A definite temperature corresponds to this equilibrium which does not depend on the path by which the systems came to this state: whether directly from the initial methane and oxygen or through the intermediate formation of acetylene. It is clear, therefore, that the more acetylene there is in the combustion products, the higher their temperature must be.

Kinetics of Acetylene Formation

Despite the large number of papers devoted to the problem, the kinetics and mechanism of the formation of acetylene by the thermal decomposition of methane do not appear to have been studied widely. A detailed review of the papers in this field was published not long ago by Krammer and Happel,[5] but the kinetics of acetylene formation by incomplete combustion appears not to have been investigated, although there are a few papers in which this question has been given special attention. Thus Benedek and Laslo[3] put forth some arguments in favour of the formation of acetylene by incomplete combustion during the interaction between formaldehyde and methanol. Kydd[6] investigated the formation of acetylene in a flame by taking gas samples. However, the data published by Kydd are too scanty to permit any useful conclusions to be drawn from them.

Owing to the fact that acetylene occurs in a flame, and at a very high rate, investigation of the kinetics of the process encounters considerable experimental difficulties. By way of a first step in this direction, a study was made of the structure of the Bunsen flame of methane burning in oxygen by taking and analysing gas samples in the region of the inner cone.[7]

Fig. 2 shows the results of analysis of the combustion products sampled along the vertical axis of the flame in the region of the inner cone apex when burning a mixture containing 43.5% O_2, 54.8% CH_4 and 1.7% N_2 in a divided-flame burner.

Examination of the curves presented in Fig. 2 shows

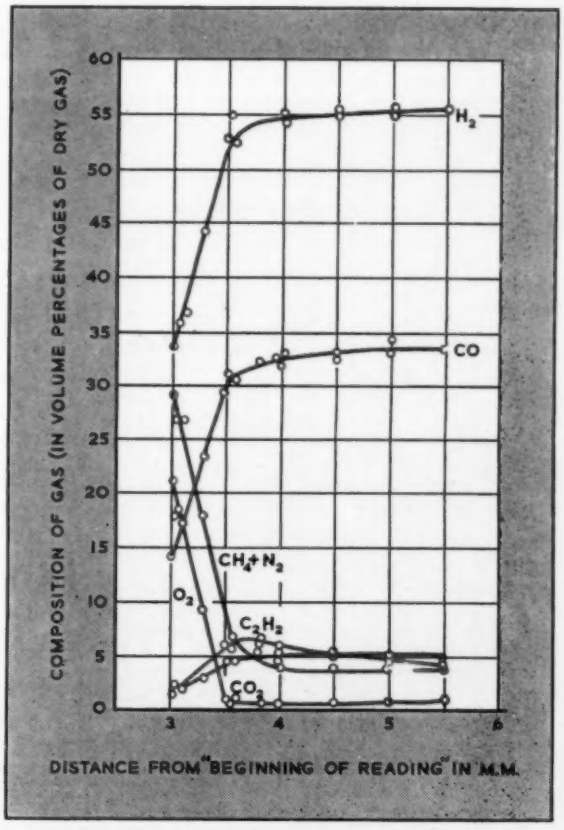

Fig. 2. Composition of products of combustion at different points on the vertical axis of the flame.

that the greater part of the methane and the oxygen reacts within a very small section of the flame, from $X=3.0$ to $X=3.5$ mm (X is the distance along the flame axis). It is in this section that all the reaction products, viz., CO_2, C_2H_2, CO and H_2, are mainly formed. Actually the combustion zone is evidently narrower, because the combustion front is inevitably deformed somewhat when the sampler is introduced into the flame. Similar results are obtained with different compositions of the initial mixtures, the concentration of acetylene decreasing as the oxygen content rises.

The experimental results obtained show that the reaction of incomplete combustion of methane and oxygen, accompanied by considerable acetylene formation, is accomplished for the most part within a zone a few tenths of a millimeter wide. Beyond this zone, above the apex of the inner cone, the reaction proceeds much more slowly. Beyond the oxygen zone the acetylene content increases slightly, reaching a maximum at a distance about 0.3 to 0.4 mm away from the tip of the oxygen zone. After this the acetylene concentration begins to drop.

To study the initial stages of the reaction, experiments were carried out in which the initial gaseous mixture was ignited quickly and simultaneously over its entire cross-section. These experiments also showed that at the beginning only CO, H_2O and CO_2 form in the oxygen zone, the formation of acetylene and ethylene from the unburnt part of the methane beginning somewhat later. It may be concluded, therefore, that the formation of acetylene takes place mainly at the end of the oxygen zone and ends in its direct vicinity on emerging from it.

Fig. 3 shows the temperature distribution along the vertical axis of the flame (curve 1) for a mixture containing 57% CH_4, 41.3% O_2 and 1.6% N_2. In the oxygen zone the temperature grows rapidly and then remains almost constant and equal to approximately 1850°C. Fig. 3 also

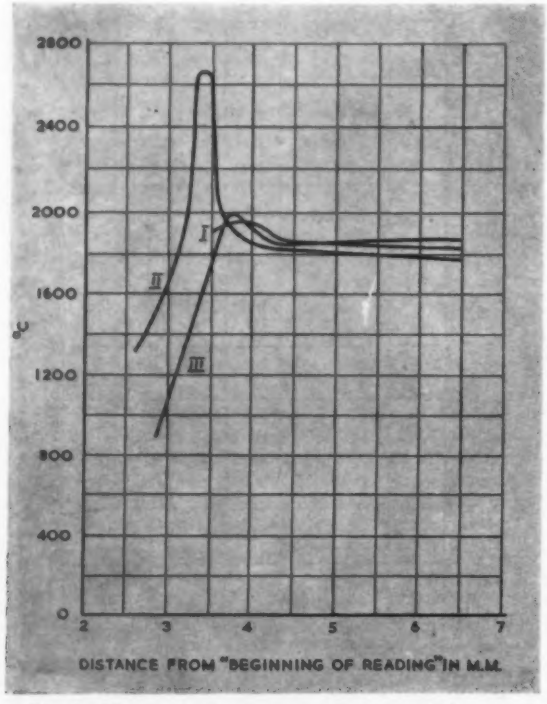

Fig. 3. Change in temperature along vertical axis of the flame. (1) Experimental curve. (2) Calculation of equilibrium of water-gas reaction. (3) Heat balance calculation.

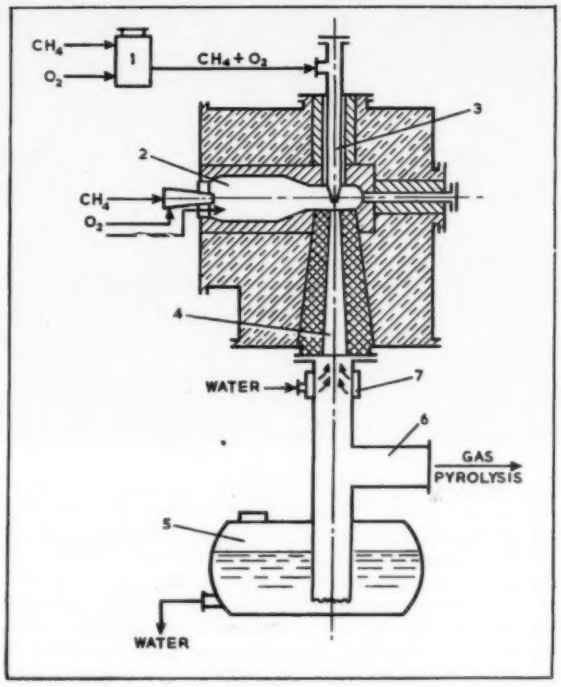

Fig. 4. Experimental furnace: (1) mixer; (2) furnace chamber; (3) blast pipe; (4) reaction channel; (5) hydraulic seal; (6) outlet of gas of pyrolysis; (7) tempering chamber.

presents two curves obtained by calculation, using experimental data on the composition of the gas. Curve 2 was obtained by calculation with respect to equilibrium between the reaction components of water gas (the temperature was determined by tables according to the value of the ratio $\frac{PCO \cdot PH_2O}{PCO_2 \cdot PH_2}$); curve 3 was found from the thermal balance with no allowance for dissociation

The considerable divergence between curves 2 and 1 for values below $X=3.7$ shows that, in the oxygen zone, the reaction components of the water gas are not in equilibrium. Here carbon monoxide and water formation predominate, and their content considerably exceeds the equilibrium content corresponding to the temperature observed. Just beyond this zone, however, curves 2 and 1 merge, showing that equilibrium is established in the water-gas reaction in the direct vicinity of the oxygen zone. This result proves the justifiability of applying the above-described method of thermodynamic calculation to acetylene formation by incomplete combustion with allowance for the water-gas reaction equilibrium.

Turbulent Flow Furnace

In Sachsse furnaces the acetylene is produced in a laminar or slightly turbulent flame. Grinenko[8] has demonstrated the possibility of preparing acetylene by the incomplete combustion of methane in oxygen with a highly turbulent flow of the methane-oxygen mixture in the duct. Fig. 4 is a diagram showing the design of a pilot furnace for this purpose.

The heated methane-oxygen mixture emerges from the nozzle at a high speed (up to 350 or 400 m a sec.), is ignited and passes into the reaction duct where turbulent burning takes place. Continuous ignition of the emerging stream, i.e., stabilisation of combustion, is accomplished

by introducing laterally additional oxygen heated to 750-800°C. The stabilising oxygen is heated by burning a small quantity of methane in it in an additional burner. The consumption of stabilising oxygen is 5 to 10% of its total consumption.

Owing to smaller heat losses, the oxygen consumption in the Grinenko furnace is a little lower than in the Sachsse furnace, but the acetylene yield and the composition of the resulting gas are practically the same. Analysis of the combustion products along the length of the duct showed results similar to those obtained for laminar combustion: the acetylene forms at the end of the oxygen zone and its maximum content is observed just beyond it. Apparently the mechanism of acetylene formation for turbulent is the same as for laminar combustion.

True, the elementary mechanism of the reaction is entirely unknown to us. It can only be assumed that what takes place is the interaction of free radicals and possibly in a series of chain reactions. Investigation of this problem is of great interest, because although acetylene is an intermediate and unstable product, it forms in quantities commensurable with the quantity of stable carbon monoxide formed. The reason may be that combustion in an insufficient supply of oxygen results in a large quantity of free radicals which yield acetylene with very great ease. Therefore, the acetylene yield is determined entirely by the mechanism of the combustion process, and the maximum yield is preserved by rapid quenching of the reaction products.

Available experimental data show that, up to 1200°C, the decomposition of acetylene into carbon and hydrogen (2) is much faster than the conversion reactions (3) and (4). Therefore, the chief decomposition products of acetylene are hydrogen and carbon black. It should also be stressed that in the combustion of the methane-oxygen mixture carbon black is formed almost exclusively through acetylene. Practically no carbon black is formed directly from the combustion of methane with oxygen. Therefore, the quantity of carbon black formed during the reaction is a measure of the degree of decomposition of acetylene.

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Perforated Plate Discharge Coefficients

IN a recent article on the "Design of Sieve-type Distillation Plates" by Dr. Eduljee[1] an equation was given for estimating the pressure loss across a plate under operating conditions. For design purposes, pressure drop is considered to consist of the "dry plate" pressure loss, the head of clear liquid above the perforation plates, a head of liquid equivalent to $\frac{1}{2}$ in. water which is added to bring pressure losses calculated on the basis of the first two items into line with observed losses. For estimating the "dry plate" pressure loss, values of the orifice coefficient are required.

Since the appearance of Dr. Eduljee's paper, some further results on "dry" pressure losses have been published recently which supplement the data already given.[2] The authors of this recent work, Kolodzie and Van Winkle, evaluate the orifice coefficient defined by the equation

$$v = \frac{C}{Y}\sqrt{\frac{2g(-\triangle R)}{\rho_D\,[1-(A_F/A_D)]^2}}$$

where A_D = cross-sectional area of column;
A_f = free area of plate;
C = orifice coefficient;
g = gravity constant;
v = average fluid velocity in the orifice;
Y = average expansion factor for the fluid (for most cases=1);
ρ_D =density of vapour;
$\triangle p$ = pressure loss.

The variables which were considered to affect the coefficients were fluid velocity through the orifice v, fluid density ρ, fluid viscosity μ, hole diameter d, hole pitch P, free area of plate and maximum possible free area of plate after its entire surface A_t was perforated. By dimensional analysis:

$$C=f\left[\left(\frac{d\,v\,\rho}{\mu}\right)\left(\frac{d}{P}\right)\left(\frac{T}{d}\right)\left(\frac{A_F}{A_t}\right)\right]$$

The effect of each of these groupings was investigated. The coefficient is affected also by the shape of the upstream orifice edge and by the position of the pressure taps. In the experiments the position of the latter was kept at 3 in. on either side of the plate and the shape of the upstream edge of the orifice was made the same for each perforation.

The plates used in the investigation were 3.78 in. in diameter; perforations were of $\frac{1}{16}$, $\frac{3}{32}$, $\frac{1}{8}$, $\frac{5}{32}$, $\frac{3}{16}$ and $\frac{1}{4}$ in. diameter. Plate thicknesses were 0.081, 0.125, 0.1875 and 0.25 in. and the holes were pitched to give pitch-to-hole diameter ratios of 2.0, 3.0, 4.0 and 5.0. The investigations of Kolodzie and Van Winkle show that the orifice coefficient becomes independent of Reynolds number at values of the latter above 3500. For distillation, the normal range of Reynolds number encountered in practice is between 3500 and 15,000. For equilateral triangular pitched perforations, these workers concluded that the discharge coefficient could be related to the geometry of a plate by the expression $K=C\left(\frac{P}{d}\right)^{0.10}$, P=pitch of holes, d=hole diameter, where K is constant for a particular plate thickness (T). K was found to vary with $\frac{T}{d}$ as follows:

$\frac{T}{d}$ =	0.4	0.5	0.6	0.8	1.0
K =	0.762	0.805	0.882	0.933	0.955
$\frac{T}{d}$ =	1.3	1.6	2.0	2.4	
K =	0.970	0.975	0.977	0.977	

The values of the orifice coefficient for $\frac{T}{d}=1$ for different values of $\frac{P}{d}$ is as follows:

$\frac{P}{d}$ =	2	3	4	5
C =	0.892	0.850	0.830	0.812

The highest values of the discharge coefficient are obtained when $\frac{T}{d}=1$, when $\frac{P}{d}$ is 2 or less, and when the ratio $\frac{A_f}{A_t}$ lies within the range 0.60 to 1.00 (A_t=maximum free area possible on a plate).

The coefficient is unaffected by the distribution of holes on a plate provided A_f/A_t is less than 0.60. In practice the value of this ratio is usually between 0.60 and 0.70.

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BALL-MILL GRINDING — PART I

The mechanism of the breakage process in ball-mill grinding is discussed along with a critical review of existing laws, theories of size distribution and breakage probability

by Ir. J. NIJMAN

ALTHOUGH it is generally recognised nowadays that neither Rittinger's law nor Kick's law gives a true picture of the energy/new surface relation in crushing and grinding because of the over-simplified assumptions on which both laws are based, the controversy between them has led to extensive research on energy consumption in many kinds of size reduction.

The need for empirical knowledge in this field is great because of two main theoretical difficulties. First, there is no general physical rule for predicting the size distributions, and, secondly, the breakage process accounts for only a small proportion of the total energy involved, especially in grinding mills. A number of size distribution curves have been proposed, representing, at one extreme, overall distributions after an indefinite number of breaking events in ball mills, and, at the other, distribution laws for experiments on single particles in a drop-weight-apparatus. Furthermore, the energy-consumption per unit of surface produced has not only been the concern of practice; research in the fields of breaking mechanism, stress and strain theory, impact time, etc., is still one of the major concerns of laboratory-scale research.

As a result of the scanty theoretical knowledge, scaling up is more or less empirical, although recently it has been the subject for a number of more theoretical papers. The main reason for the lack of research on scaling up of ball mills may be that, until a few years ago, no law was known describing the probability of breakdown, e.g., the velocity of the breaking process. The influence of the many variables in the milling process on this probability is still insufficiently known.

Mechanism of a Ball Mill

Since the extensive researches of Fisher[1] and Gow *et al.*,[2] the behaviour of the balls in a ball mill is fairly well known for different rotation speeds of the mill and different ball loads. The following points may be emphasised. As their experiments were carried out with mills filled with balls only, the true action of a mill must be estimated from experiments with mixtures of balls of different sizes. From these experiments it has been found that at the normal percentage of loading the bigger balls do not reach the wall. The smaller balls present need all the available wall surface. The same can be assumed to be true for mills loaded with relatively big balls and with a charge of relatively small material.

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Symbols

D = diameter of ball mill;
N = number of rotations/min;
H = weight of solids in a size fraction;
H_o = weight at $t = o$;
H_t = weight at time t;
K = breaking velocity constant;
R = % of solids on sieve of aperature x;
t = time;
x = sieve size; and
n, F, p, empirical constants.

The critical rotation speed of a mill is defined as the one above which the balls maintain contact with the walls during a complete revolution. However, this critical speed is only well defined when the mill is filled in such a way that all material present can contact the wall, that is when there is only one row of balls. As the surface available is proportional to the diameter (D) and the volume of the mill to D^2, it follows that the bigger the mill the smaller is the filling percentage which permits more than one row of balls to be formed at the critical speed. This means that at constant filling percentage the action of the balls may be different for different diameters of the mill. This is probably one of the reasons for Mittag's statement[18] that an experimental mill must not have a diameter smaller than 0.8 m. When several rows of balls are present the critical rotation speed for the second row will be higher than the one for the balls close to the wall.

Thus the critical speed is no longer well defined, a point clearly illustrated by Connor,[4] who plotted the eccentricity of ball charge against speed relative to critical. The eccentricity does not fall to zero at the critical speed, nor is the break in his lines independent of ball charge. Moreover, in some cases eccentricity will still occur above critical speed. As it can safely be assumed from the foregoing that the behaviour of the balls depends on the filling percentage, amount of charge, diameter of the mill and rotational speed, it is clear that the value of the latter,

at which the probability of breakage is at a maximum, varies widely from experiment to experiment (e.g., Gow, *et al.*, 65% of critical speed, Djingheuzian[3] 80%). Existing laws, e.g., Fisher's formula $N_{opt} = \frac{32}{\sqrt{\text{diam}}}$, account only for one, and at best but few of the many variables met with in actual practice.

Another difficulty is that the extent to which the ball charge in an empty mill is lifted against the casing is a function of the friction between balls and casing and of the filling percentage of the mill. This means that the well-known pattern of the movements of balls in empty mills may be changed considerably by the presence of the feed.

It is not unlikely that this pattern changes during milling through the disappearance of the bigger size particles from the feed with time. Since the presence of liquid reduces the friction considerably, the techniques of dry and wet grinding are not comparable. However, influence of the amount of liquid present will not be considered in this article.

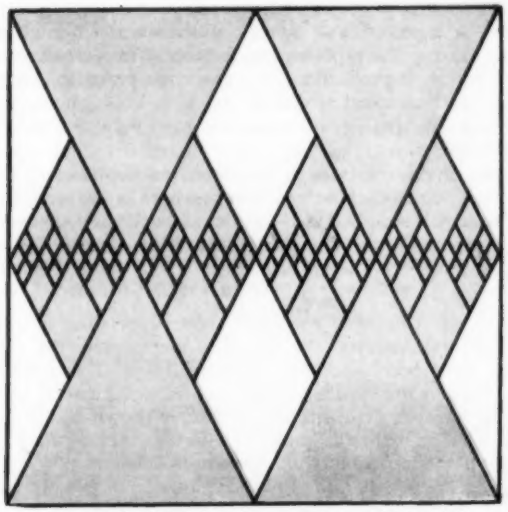

Fig. 1. Idealised breakage pattern obtained by drop-weight method (from Andreasen[11]).

From the statement that there is an optimum rotation speed at which the probability of breakage is at a maximum, the question arises what action of the balls causes this optimum. It is clear that there is hardly any breakage at very low speeds and at the "critical" speed. Between these limits an increase in rotational speed will cause the balls to roll back in bulk once they have been lifted to some extent by the centrifugal and friction forces. At higher speeds cascading begins: the balls are carried up, but not near the top of the casing, and fall back, jumping and rolling over each other. At still higher speeds the balls near the wall almost reach the top and fall down independently—or semi-independently (cataracting). Then they may fall either upon the bottom of the mill or upon other balls and the feed on the bottom of the mill. There is no strict difference between cascading and cataracting; in fact, the balls in the centre of the mill are still cascading when cataracting takes place. It must be assumed that the movement of the feed is virtually the same.

As a result of the different movements of the balls, it is generally accepted that two kinds of size reduction take place: abrasion of the particles caused by friction (feed between balls or feed between ball and casing) and breakage caused by cascading and cataracting. Size reduction of harder and bigger particles is caused by breakage. In fine grinding particles are mostly formed by abrasion because the falling ball is cushioned in a bed of very fine particles; consequently, the techniques for fine and coarse grinding are different.

Under normal working conditions, and for coarse grinding, the movements in a ball mill will be those of cascading, plus some cataracting, but not to the maximum extent. This seems to indicate that both mechanisms cause breakage; that is, balls with energies varying from zero to that corresponding with the maximum falling distance in the mill may take part in the breaking action. It is still an open question what the numerical distribution of these "hits" is at different energy levels and what proportion of them plays an active role in the breakage process. In fine grinding the rolling of the balls is of more importance. This often means a higher filling percentage of the mill, especially in wet grinding where the cascading balls are still further cushioned by the presence of liquid.

The addition of balls of small diameter, especially when eccentric and with a non-regular surface, gives a stronger abrasive effect in coarse and fine as well as in dry and wet grinding. The breaking velocity of the feed is not much influenced, but the size spectrum of the particles produced is changed in the direction of smaller particles. From a closer study of this phenomenon, Langer[38] believes that practically every size distribution can be obtained by the choice of the right combination of ball sizes.

The Breaking Process

Attention is here confined to conditions where the abrasive action of the ball mill is negligible in comparison with the breaking action. Moreover, the particles referred to must be brittle; that is, no plastic deformation takes place before and during the breakage event. It is generally accepted nowadays that under these conditions, and whatever the kind of size reduction, the breakage process can be described by two different functions.[5] The first is the probability of breakage and the second the size distribution of the particles after the breakage event. It is clear that, to use this as a working hypothesis, one has to

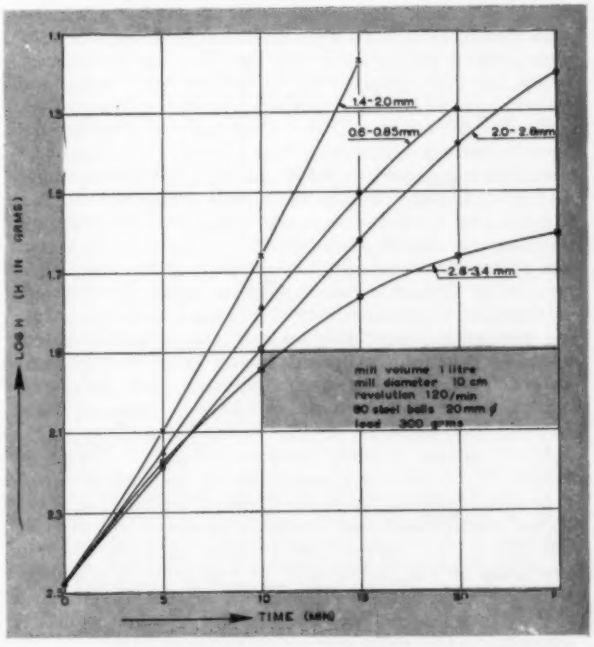

Fig. 2. Results of experiments on ball milling of sand particles broken in a pre-milling treatment.

consider single acts of breakdown, or a process must be divided into a series of breakdown events.

From this point of view, ball-mill grinding can be seen as a complicated process, in which every discrete step can have its own probability and its own particle distribution law, but it is not known *a priori* whether the two functions are independent.[5] Moreover, as the load of the different mills can vary widely in physical properties, an empirical size distribution law will not show the exact size distribution for every substance and after every milling time. This is probably the reason that, mostly for materials defined as "brittle", so many empirical laws have been proposed. One of these, found by Rosin and Rammler[6] and Sperling,[7] has been given a theoretical background by Bennet,[8] based on Lienau's theory[9] of multiple random breakage of one-dimensional bodies. The Rosin and Rammler law is suitable for predicting size distributions after fairly long milling times, although Lienau's theory is open to serious objections because it has to assume that a particle breaks at "a large number" of spots—say 15—in every direction at the same time. This is not in accordance with Taylor's[10] findings that a size reduction of 4 to 1 is difficult to obtain. Moreover, the law does not mention the probability of breakage, which is assumed to be equal to unity. Thus it is more of practical importance than theoretical.

The above-mentioned theory based on two functions seems to be the best approach to the breakage problem, but, as has been clearly stated by Lowry and Epstein, all variables influencing one or both of the functions have to be studied.[5] This means that only very simple breaking events are at present open to theoretical study. The almost classical example of such a simplified process is the drop-weight apparatus used by Andreasen.[11] The particles used were cubic, and rested in a bed of gelatine, to make reconstruction of the breakage pattern possible. The resulting idealised fissure pattern as given in Fig. 1 is well known. Smekal[12] obtained the same results in a similar manner. In this case the probability of breakage is one; there is only one breakage event, and even then the resulting distribution can only be described by a simple law for part of the distribution curve. Smekal's explanation is that there is an even distribution of particles over each size group with an exception for very small particles, which are not formed, while big particles "break too early".

Bennet, Brown and Crone[13] used the dropping of coal particles on a concrete floor as a simplified breakage process. They again took care that the probability of breakage was equal to unity. Furthermore, they recognised the fact that the way in which forces are applied may influence the resulting size distribution. Their results for a single breakage event gave a straight line on plotting the log weight percentage through a sieve against log sieve size. Brown[14] calculated a distribution law for the case when this breaking mechanism was applied several times, and in successive steps as originally proposed by Heywood.[15] The same approach is used by Lowry and Epstein,[5] while the mathematics for a more simple calculation technique have recently been given by Broadbent and Callcott.[27]

In the course of their research, it has been found by Bennet, *et al.*, that two types of particle are formed during a breakage process: particles in which cracks have penetrated (complement) and particles in which cracks have not penetrated (residue). Both follow different distribution laws, as has been found by Taylor.[10, 15] The distinction between the two is rather indefinite, but Taylor states that it is a useful one, because the question concerns statistical distributions and not individual events.

From all the experiments mentioned above it may be concluded that the energy of impact, provided it exceeds a certain minimum, is rather unimportant for the resulting size distribution. This is confirmed by Charles,[17] who found that the type of distribution remained the same when different energies were applied at constant impact time, but the size distribution curve slightly shifts to smaller sizes with higher impact energies. Changing the impact time by using a bullet fired from a gun instead of a dropping weight, the distributions found could still be represented by a similar distribution law (the Schuhmann law[19] was used in this case) but with a different slope. From these experiments it may be concluded that the slight differences in impact time encountered in ball milling are of no importance to the resulting size distribution. The experiments were carried out on Pyrex-glass cylinders.

An additional difficulty in interpreting the course of grinding is that energies lower than and equal to the minimum energy needed for breakage are exerted. As a particle can break during the last of several blows in succession, cracks being caused by preceding ones, the structure of the particle will be of fundamental importance for the resulting size distribution when low energies are applied. As Smekal pointed out some twenty years ago, our knowledge of the structural influence was—as it is still—insufficient. The problem may be solved for some special case, but its complications are too widespread to expect a general theoretical size distribution law as long as the influence of particle structure has not been taken into consideration.

Most of the correlations based on practical experience, however, do not show much difference in the resulting size distributions. One of these, the aforementioned Rosin-Rammler law, is of wide importance. In its simplest form:

$$ln\left(ln\frac{100}{R}\right) = n\ ln\ x - n\ ln\ F \qquad \ldots.(1)$$

it has two empirical constants, both depending on the material used and on the breaking mechanism; the constants have been interpreted kinetically by Theimer.[20] It resembles to the Andreasen law and is well adapted to fit a large number of distributions. This is shown by its successful use in ball-mill grinding,[18] although the law does not mention the probability of breakage which is not equal to unity in a ball mill. From Equation (1) follows that for $x=F$, $R=\frac{100}{e}=36.79$. For that reason, F can be used as a measure of the fineness of the material.

Fig. 3. Cracks present in a particle after breakage: point A, the centre of attack, is the origin of a series of cracks.

In technical and small-scale milling the probability of breakage is never equal to unity. This means that the speed at which size reduction occurs must be known. Several ways of expressing this speed have been proposed, some of which are mentioned here. The percentage passing a fixed mesh size used in practice, is one of the simple ones. The value of F in the Rosin-Rammler equation gives a clearer picture, because it takes account of the original size of the particles.

More complicated expressions are given by Hüttig, *et al.*[21] One of these is $M=\frac{dH}{dt}$ for every size x: this time function gives the amount dH per time dt in going from a size larger than x to one smaller than x. However, H cannot be found by integration unless the probability and distribution laws are both known for every particle size. The distribution law can be neglected and the probability can be found experimentally for the largest size group of the original particles present. For this group, $\frac{dH}{dt}$ is always negative and it was originally found by several investigators[23, 24] that for the disappearance of particles a probability law analogous to the expression for a mono-molecular chemical reaction is valid:

$$-\frac{dH}{dt}=KH \qquad \ldots.(2)$$

When one is largely interested in the disappearance of the larger particles during grinding, it is evident that Equation (2) can be useful. As K is, in principle, a function of particle size, the size fraction considered must be rather narrow. Furthermore, one of the conditions for the validity of the expression is that no fragments of the original particle have remained in the original size fraction after breakage. Müller[22] originally thought that a similar law could hold for the whole size range, but it is now clear that this can only be approximately true, and then under special conditions only.

This means that the particle size spectrum must be divided up into narrow size groups when the probability of breakage is to be considered. Then for the largest size group only, Equation (2) can be used. The behaviour of the other groups can be calculated indirectly. Sedlatshek and Bass derived mathematical expressions for $\frac{dH}{dt}$ for four size fractions in succession. In principle, this is possible with an unlimited number of fractions, but the results become inexact after three or four groups have been calculated. As particles from the coarser fraction break into the following groups, a distribution law has to be applied or found experimentally. Sedlatshek's treatment requires several assumptions to be made and, for this reason, the approach used by Hüttig and his collaborators[24] is preferable, as they were able to find K experimentally for any of the original size fractions by use of radioactive indicators.

In most experiments there is an end effect. When cracks and fissures are present in the original particles these cause extra breakage. The effect disappears after 10 to 15 minutes' grinding.[25] The proposed law has several limitations. For example, after a certain milling time the breaking effect of the balls becomes less, because breakage is hindered by the relatively large amount of fines present. This influence on K for the bigger particles has been confirmed by Sales[25] but seems to be present only after prolonged milling times.

A serious practical defect has been found by Sales[25] from experiments on sand. He was unable to obtain a straight line under every milling condition when plotting Equation (2) in its integrated form:

$$ln\ H_o-ln\ H_t=Kt \qquad \ldots.(3)$$

Both positive and negative values of $\frac{dK}{dt}$ were shown to be possible, but no explanation was brought forward. It was concluded that the mono-molecular reaction mechanism was too simple, and for this reason Sales used the expression:

$$-\frac{dH}{dt}=KH^p \qquad \ldots.(4)$$

Several values of p other than unity were tried out. Graphically, this gave straight lines, but for each line a different value of p was required. The mathematical background for some of these more complicated mechanisms has been given by Theimer[30] and Brenner and Vidmayer.[28] For values for p other than unity in Equation (4), Sedlatshek's theory for the probability of breakage has not been replaced, since in such cases the physical nature of the process is not yet clear.

At present there is not enough evidence to discard the mono-molecular reaction theory. In fact, during an extensive research in 1-litre laboratory ball mills no serious deviation from Equation (3) could be found when milling single size fractions. The coarse sand particles used were ground in the same mill beforehand, in such a way that only particles broken during pre-milling were used in the experiments of Fig. 2. This was to make quite sure that all particles used in the actual experiments had been adapted to the milling conditions. Cracks will always be present after breakage, as can be seen from Fig. 3. The particle shown has been broken by a dropping weight with the centre of attack at point A, from which a star of cracks extend. The broken surface along A-B has been reconstructed; the lower part of the particle has disintegrated to dust. The cracks along the lines AC and AD support the belief that cracks may be present after a breakage event.

From the example given in Fig. 2, it can be concluded that Equation (3) is valid for all experiments, except those on particles of more than 2-mm sieve size. These are too big for this type of ball mill and, as a result, the inhomogeneity of the strength of the particles shows itself: with time the weaker particles disappear and the stronger ones remain or break at a smaller rate. Thus K diminishes with time, and it is noteworthy that this does not happen with the smaller fraction. Consequently, under normal milling conditions, the different size fractions can be regarded as homogeneous in strength.

From these researches we may conclude that K is a convenient measure of the probability of breakage and, therefore, of the speed at which the coarser particles disappear. Thus, the Rosin-Rammler equation can be used to estimate the particle spectrum of the ground product, and Sedlatshek's equation gives expressions for the amount of the original feed that is still left.

It has been confirmed by the author that a size reduction of 1 in 8 of the coarsest feed fraction can still be calculated with reasonable accuracy in this way. Approximate calculations will cover a greater reduction.

Conclusion

The following points are of direct importance in the practice of ball-mill grinding. Practically all of the theoretical knowledge on ball milling is confined to the breakage of brittle particles, where abrasion can be neglected. Even for this simplest case of grinding there is as yet no knowledge of the size distribution after one breakage event in a ball mill, because for different materials the distributions may not be the same. As the broken material exerts considerable influence, it will probably be necessary to determine this size distribution for

each material, especially when—as in continuous grinding—one is primarily interested in the amount of oversize after milling.

No mention has been made of the many studies on the ways in which particles can break, nor of the Rittinger-Kick controversy, a problem closely related to the breaking mechanism. Although a considerable number of articles have appeared, giving valuable information on these special subjects, our knowledge is still insufficient to provide a theoretical understanding of ball-mill grinding.

From this it follows directly that the energy/new surface relationships described in the literature are of little use. This is the more true because, in any case, roughly 99% of the energy input is lost by ineffective work in the ball mill. It is at present therefore much more practical to find the optimum throughput *versus* total energy consumption during milling, while fundamental research should give results in the form of throughput *versus* time curves. It is true that extensive research has been carried out to find the optimum working conditions when different kinds of material are being milled but, owing to the inconvenient fact that even ball load, ball diameter, ball density, diameter of mill, rotational speed, kind of feed, feed size and feed load do not exhaust the variables in discontinuous grinding, it can safely be stated that the optimum conditions are hardly every known.

In continuous grinding, additional possibilities are change of medium residence time and choice between the

Fig. 4. A closed-circuit ball-mill grinding plant with air classification, manufactured by International Combustion Ltd., Derby, and installed at the Hackbridge Mills of Boots Ltd., Nottingham.

use of one, two or even more mills in series, with or without sieves for stopping big particles to be returned, and/or separation of smaller particles ready for use. Moreover, the different types of mill, the kind of lining, ball wear, etc., have not even been considered. It must be said, however, that quite a lot of information is available, although there are still big gaps to be filled.

The Rosin-Rammler equation gives a reasonably accurate description of the size distribution to be expected for the smaller particles; Sedlatshek's theory of breakage probability similar to the mono-molecular reaction mechanism can be used to predict the time needed to grind to a previously fixed percentage of oversize. Up to now this has not been applied rigorously, even in laboratory mill grinding, probably owing to the doubts arising from Sales' work.

As the researches needed for all industrial milling operations would be too extensive for large units, the scaling up of ball mills, or the adaptation of laboratory results to continuously operating mills is still one of the major problems of ball-mill grinding. This will be dealt with in Part II of this article.

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Gas Solid Reactions*

THE CHEMICAL ENGINEER is concerned with the rate-limiting process of reactions, e.g., ore reduction where the temperature is controlled by reaction rates, by diffusion of gases and by heat transfer. When a sphere of carbon is burned below 850°C in oxygen-nitrogen mixtures, Hottel found that the rate of combustion is controlled by the chemical reaction at the solid-gas interface; above 850°C, a much-decreased temperature cofficient for the reaction which is of the order to be expected from theories of diffusion proves that diffusion of the gas to the gas-carbon interface controls the rate.

The oxidation of rectangular zinc sulphide crystals to zinc oxide by air was studied. A porous layer of zinc oxide formed on the surfaces of the crystals permits the diffusion of sulphur dioxide from the surface and provides the main diffusional resistance. The control of the rate of oxidation of the sulphide changed from chemical to diffusional above about 830°C. At temperatures above 950°C the reaction rate changes again because the evaporation and dissociation of zinc sulphide takes control and oxidation in the vapour phase follows. Prof. Denbigh plotted the rate of heat loss by convection from a solid on the same graph as the reaction rate versus temperature; the loss is proportional to the temperature difference betwen solid and gas—it is a straight-line law and under suitable conditions can cut the reaction rate curve for zinc sulphide or carbon oxidations at three temperatures. The lowest and highest temperatures of intersection are stable, the intermediate temperature of intersection is unstable because the lowest temperature is the ignition temperature.

* *A summary of a paper given on December 17 by Prof. Denbigh to the North-western Branch of the Institute of Chemical Engineers.*

PLANT FOR POLIOMYELITIS VACCINE MANUFACTURE

SPECIAL pieces of equipment used in the manufacture of poliomyelitis vaccine at the new laboratory of The Wellcome Foundation Ltd., Beckenham, Kent (see *British Chemical Engineering*, January, 1958, p. 13), include apparatus for the removal from the living polio-virus culture of carbon dioxide produced during growth, before the liquor is inactivated and further processed (see Fig. 1). The polio culture is drawn into the system under vacuum from the tank (see diagram below) and through a fine spray cone jet into the first degassing vessel (1). The dissolved gas flashes off and leaves the degasser through the vacuum line. To increase the efficiency of separation and reduce entrainment, the liquid is sprayed tangentially and the gas outlet is arranged so that a reversal of flow takes place. The partially-degassed liquid falls to the small sump at the bottom and is then sucked through the spray jets of the other degassing units (2) and (3), when further degassing takes place. A pressure gradient is maintained through the system. To meet an urgent demand the three degassing vessels were made from standard 20-litre stainless-steel pressure containers designed for beer storage.

For aseptic agitation and mixing procedures special 100-litre polished stainless-steel tanks have been designed. Two of the vessels are shown in Fig. 1 (extreme left and right) in use in the degassing process. A rotary propeller or a reciprocating stirrer working through a flexible rubber diaphragm may be fitted.

Separation of the living kidney-cells from dissected living monkey-kidney tissue is carried out in the trypsinisation battery shown in Fig. 4. The tissue is kept agitated in fluted glass-flasks by magnetic stirrers, the flutes producing a baffling action. The flow of solutions and the other conditions are adjusted precisely and the separated cells in suspension are caused to overflow a weir into a collector.

The novel construction features of the new building (see p. 13) are outlined in the laboratory's exterior (Fig. 2). The services rooms, separate from the laboratory working-space, are contained in the section of the building on the right, and the location of the inter-floor voids from which (Fig. 3) are supplied the laboratory services (bacteriologically filtered air, refrigeration, vacuum, electricity, water, gas, etc.) can also be seen.

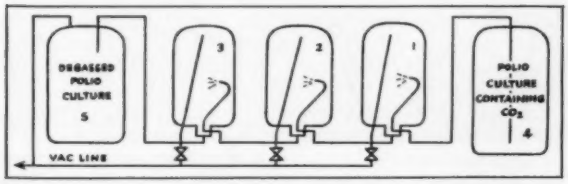

Diagram of the virus-culture degassing plant.

Fig. 1. Degassing apparatus for living culture.

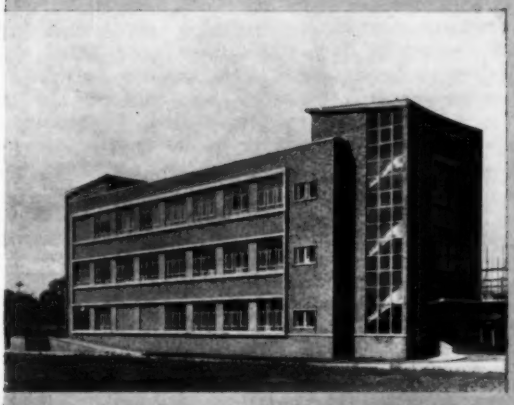

Fig. 2. General view of the manufacturing laboratory.

Fig. 3. Interior of a services-void, showing spaciousness.

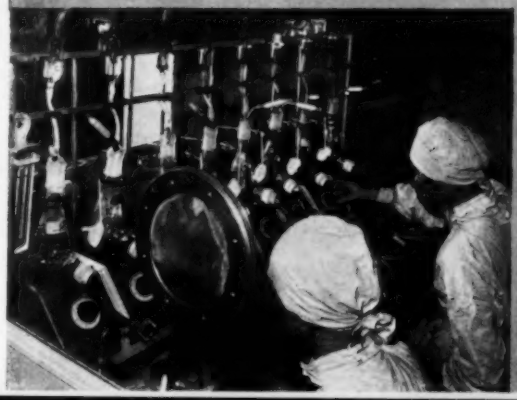

Fig. 4. Trypsinisation apparatus, assembled from laboratory-scale equipment. →

RESEARCH ON COAL

A review of some developing themes of interest to the chemical engineer

by I. BERKOVITCH, Ph.D., F.R.I.C., A.M.I.Chem.E.

THERE is a fresh wave of scientific interest in coal, but the balance is shifting. While there are many lines of research connected with coal in the ground and with improving its use as a fuel, there is now greatly increased attention to treating it as a valuable raw material for processing. It is the last of these categories and—particularly the longer-term steps towards "valorising" coal—which sets the main scope of this review. In some cases work is at a middle stage of process development; in others it is at the laboratory, including the "pure science", stage.

Established carbonisation processes already deal with a large proportion of our inland consumption of coal (57.2 million tons out of a total of 218 million tons in 1956); since the war the tonnage taken by these processes has increased by about 50% and it is estimated by Coal Board authorities that the trend will continue for the next fifteen years, by which time between 75 and 80 million tons would probably be required. Current trends and possible developments in these processes and in gasification and hydrogenation have been surveyed by the N.C.B. Director-General of Research,[1] with special emphasis on production of coal chemicals.

In Britain there is no formal strategy of attack on coal research, but it is useful to open this survey with a look at the general fuel perspective and the organisation of fuel research, for work on coal is necessarily interwoven with that on fuel in general.

Prospects and Planning

It is difficult to assess the repeatedly-revised estimates for the rate of development of atomic energy. Therefore, the following figures represent trends with an uncertain time scale.

There is still an energy deficit and this is likely to continue for many years. In 1955, J. Bronowski[2] estimated that for electricity generation—a rapidly rising demand estimated to be up to 100 million tons of coal equivalent by 1975—coal would have a seller's market until 1965; by 1975 the market would be full and by 1985 the sale of coal for electricity would be dwindling. This is in good agreement with the estimates of G. H. Daniel,[3] that after other energy contributions have been taken into account the demand for coal as such would rise from 230 million tons in 1954 to a peak of about 240 million tons in 1970. Even allowing for the use of oil, "only in the following years would the pressure on coal be eased by the massive injection of nuclear power and fifteen years later, in 1985, the demand for coal would still be about 225 million tons". If there is continuing rising prosperity, these movements will include a decline in demand for domestic fuels which will be replaced by electrical home heating. This suggests treating smokeless fuels, with ancillary chemical industry, and work on more efficient combustion as a matter of urgency; improved coke for the iron and steel industry from poorer coking coals, although not discussed above, runs these fairly close, and chemicals from coal form a longer-term perspective. Yet the term cannot be too long, for more recent Coal Board estimates have suggested the possibility of some surplus small coal as early as 1965.

Organisations for fuel research in Britain have grown up piecemeal and there is considerable overlapping in their

Fig. 1. Electric resistance analogue for solving heat flow equations.

Dr. Berkovitch *has worked on the action of sulphur on coal; M.Sc. (Tech.), Manchester* 1939. *After several years on other problems, returned to coal,* 1949, *N.C.B. Scientific Department H.Q. Later, at Battersea College of Technology, worked on effects of vibrations on heat transfer from flames, Ph.D.* 1957. *Now Associate Editor of* British Chemical Engineering.

scope. It is claimed that the Ministry of Power "has a most important role in ensuring co-operation in research" between the Ministry itself, the Fuel Research Board, the Research Associations of the D.S.I.R. and the research organisations of the nationalised fuel and power industries. These bodies send in programmes to the Scientific Advisory Council of the Ministry, which then tries to minimise overlapping and notes potentially-useful fields of research uncovered. The Ministry then sponsors research where it overlaps the boundaries between individual fuel industries or may be outside the ambit of any existing industry; for example, in the large-scale exploitation of peat as a fuel. There are also many collaborative projects between the different organisations. The arrangement probably works better than its untidy structure would suggest.

The cost of research borne directly by the National Coal Board exceeds £1½ million per annum. The total expenditure disclosed by all public and semi-public bodies amounts to a little over £3 million per annum. This may be compared with the total revenue of the coal and associated industries, which is of the order of £1,000 million per annum. These figures exclude work on atomic energy or on oil as a fuel.

Some Physical and Chemical Studies

It is almost a truism that major changes in coal processing will be likely to come from better understanding of its structure. This is therefore a useful starting point.

A coal seam may contain up to four banded constituents and these, in turn, may contain varying proportions of fine components. To overcome the difficulties posed by the heterogeneous petrology of coal, most physico-chemical studies have been made on vitrinite—the most common and the most "coalified" fine component; that is, the most completely transformed from the original plant remains—or on bright coals containing a very high proportion of vitrinite. It will, of course, be necessary to extend this work to the examination of the other fine components in order to be able to relate the results to ordinary commercial coal of mixed petrographic composition, but the notes in this section tend to be true largely of the vitrinites.

X-ray crystallographic studies[4,5] have given considerable insight into the regular arrangements of carbon atoms in the "skeletons" of coal molecules and into the way they change on carbonisation. They have extended and added precision to concepts already developed on purely chemical evidence. Initially, the skeletons appear to consist of rafts of fused hexagonal rings of carbon atoms stacked roughly parallel to one another. The number of rings in a raft and the number of rafts in a pile are both smallest for low rank coal (two to four fused rings) and largest for high rank (up to thirty fused rings). Altogether 70 to 80% of the carbon is in these rafts. The rest of the carbon is in "edge groups" which surround the rafts and lock them together. When the coal is heated the first effect is to break off some of the edge groups and so to allow the rafts to grow by adding more rings and eventually to coalesce.

The edge groups give coals most of their characteristic properties, both as fuels and as sources of by-products. It is important therefore to get to know as much as possible about them. For this purpose other techniques than X-ray diffraction must be used. Infra-red radiation gives information about the vibrational frequencies of substituent groups and permits at least parts of the disordered regions to be identified. Also, indirect approaches are being attempted by using nuclear magnetic resonance. Preliminary studies in chemicals of known structure containing both aromatic rings and aliphatic edge groups suggest that the method might be applied to finding the ratio of aliphatic to aromatic groups in unknown substances including coal.

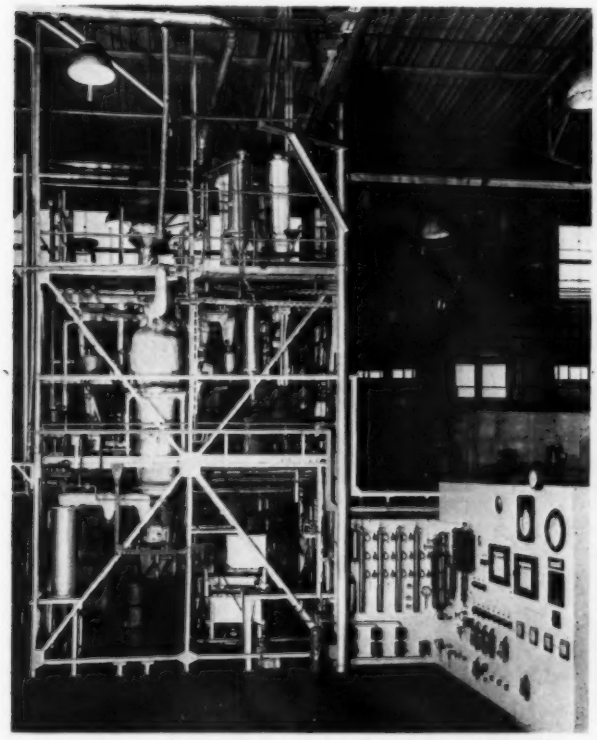

Fig. 2. 8-in. diameter fluidised carboniser at N.C.B.'s Coal Research Establishment, Stoke Orchard.

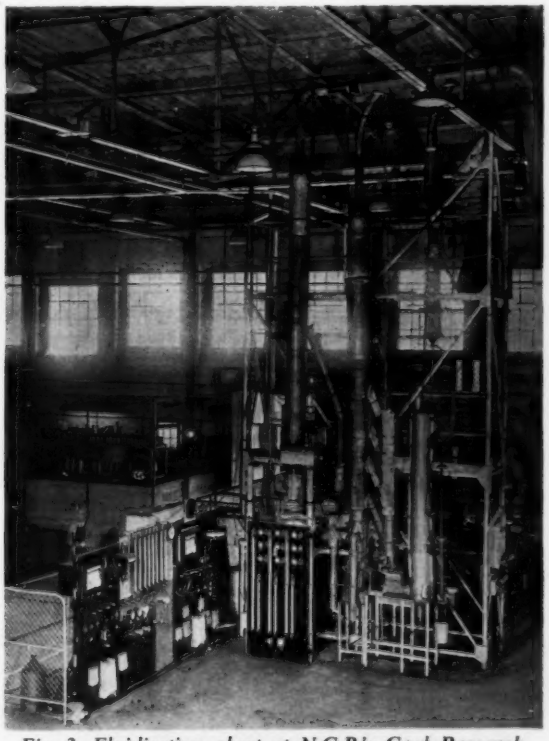

Fig. 3. Fluidisation plant at N.C.B.'s Coal Research Establishment, Stoke Orchard.

TABLE 1.—Postulated Breakage of any Feed Distribution (after Brown[1])

Size grade	Size analysis of broken product from each size grade			Size analysis of any feed, f	Calculated size analysis of product, p	Matrix notation
	1 in. × ½ in.	½ in. × ¼ in.	¼ in. × ⅛ in.			
1 in. × ½ in.	10			a	$0.1a = A$	
½ in. × ¼ in.	20	10		b	$0.2a + 0.1b = B$	$\underline{\mathbf{M}} = \begin{matrix} 0.1 & 0 & 0 \\ 0.2 & 0.1 & 0 \\ 0.3 & 0.2 & 0.1 \end{matrix}$
¼ in. × ⅛ in.	30	20	10	c	$0.3a + 0.2b + 0.1c = C$	
Minus ⅛ in.	40	70	90	(by subtraction)	(by subtraction)	
Total	100%	100%	100%	100%	100%	$p = \underline{\mathbf{M}}.f$

Other studies which are hoped to give more information on the complicated fundamental structure include measurements of changes in the thermal expansion on passing between physical states and measurements of energy requirements for vibration of specimens.

Much of this type of work is being sponsored by the N.C.B. and by the Fuel Research Station in the universities. Chemical investigations of the structure of the sub-humic acids formed from coal by mild oxidation using ozone and hydrogen peroxide are in progress at Birmingham University. The aim is to degrade coal to fragments slightly more complex than the simple benzene carboxylic acids in order to indicate the types of linkage present. At Imperial College (London) the effect of treating coal at 325°C and 6000 atmospheres was reported to be an increase of carbon content from 83.6% to 85.0%, with a fall in hydrogen content from 5.31 to 5.21%. This forms part of a programme for obtaining information on the conditions for anthracite formation and the accompanying changes in structure.

In a series of papers in *Fuel* from the Dutch State Mines Central Laboratory, van Krevelen and collaborators have set out to deduce sizes of aromatic nuclei and the fractions of carbon in aromatic form from such properties as calorific values, reflectivities, densities and refractive indices of coals. Much of this work was summarised by the principal author[6] in 1954.

More recently, Dryden[7] has drawn together much earlier chemical work in an attempt to evaluate quantitatively the relations between the chemical constitution of coals and their behaviour when pyrolysed. The aim was to bridge the gap between fundamental research and practical carbonisation. Three new concepts—carbon, hydrogen and oxygen in volatile matter—were used to throw light on the mechanisms by which volatiles are formed during heating. After noting that the combined water and tar yield is in good agreement with that expected from the hydroxyl contents of coals, Dryden made the suggestion that it may be possible to increase the tar yield many times at the expense of water—"if methods can be found". There is apparently a margin on stoichiometric grounds for increasing the yield of tar to a theoretical figure of about 140 gallons a ton, but industrial yields of gas are close to those stoichiometrically possible. There is also considerable chemical margin for increasing or decreasing the yield of coke from a given coal.

A wider range with a more mechanical emphasis was covered by R. L. Brown in a paper[8] discussing industrial implications of some coal research problems. This also reported the methods by which the capillary structure of coal had been elucidated. In trying to relate fundamentals of coal breakage to performance of industrial pulverisers, a method of approach was discovered which is quoted from Brown fairly fully below.

In scaling up from bench work to an industrial process, one of the important problems concerns the relative balance of physical and chemical rate-determining processes in the two cases. A simple way of handling the situation has been found and applied usefully in coal grinding. Consider a simple problem in coal breakage as set out in Table 1. It is supposed that the broken product from 1 in. × ½ in. coal consists of 10% of 1 in. × ¼ in. coal, 20% of ½ in. × ¼ in. and so on. Similarly, with the ½ in. × ¼ in. coal, 10% of the product remains in the size range ½ in. × ¼ in., 20% in the range ¼ in. × ⅛ in. and 70% is smaller than ⅛ in. Then if (a, b, c, d), where d is ($100 - a - b - c$), are the percentages of each size grade in any feed, the size analysis of the product p is readily calculated, as shown in Table 1. Now in the array $\underline{\mathbf{M}}$ on the right, the amount of material in the product lying in the ½ in. × ¼ in. grade is obtained by multiplying the second row of the array $\underline{\mathbf{M}}$ into the feed distribution: that is

$$B = 0.2a + 0.1b + 0.$$

Thus, if we regard $f = (a, b, c)$ as the feed vector, $p = (A, B, C)$ as the product vector and call $\underline{\mathbf{M}}$ a matrix

Fig. 4. General view of the pilot Lurgi plant installed at the Gas Council's Midlands Research Station, Solihull, near Birmingham.

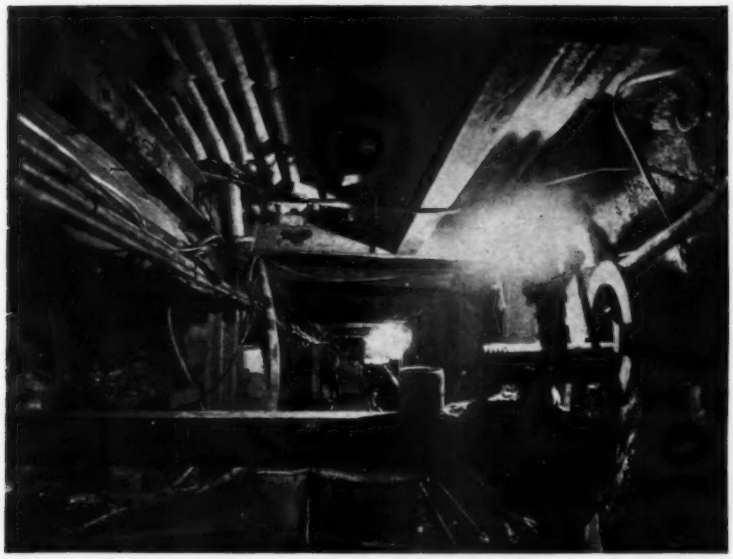

Fig. 5. Underground preparations for multiple borehole trial for underground gasification of coal showing air tubes loaded into boreholes.

operator, we can write the whole calculation down compactly as the equation:

$$p = \mathbf{M}\ f.$$

This is an equation in the usual matrix notation, so that the methods for dealing with it already exist.

This simple device can be used to elucidate quite complicated situations such as predicting mill performance in closed-circuit grinding from batch data giving the breakage in the mill and the sharpness of the cut in the classifier. It treats the histogram of the sieve analysis directly.

The method was later applied in detail by Broadbent and Callcott in a series of papers.[9]

A different domain of process possibilities is revealed by the survey of major and minor (mainly) metallic constituents of the dispersed mineral matter in coal seams which the Coal Survey branch of the N.C.B. is carrying out. At least 38 elements will be covered, ranging from the obvious aluminium, iron and calcium to germanium, molybdenum, titanium, vanadium and zirconium.

Carbonisation and Briquetting Investigations

At the N.C.B. Coal Research Establishment the emphasis is on extending means of producing solid smokeless fuels for both open grates and closed domestic stoves. Papers on some of this work were presented at a conference[10] at the establishment in 1956—where J. Bronowski emphasised that the new processes were being considered as steps towards the future exploitation of the chemical content of coal—and a general survey of its scope has been presented by W. Idris Jones.[11]

Fluidised carbonisation is being developed because it is continuous and gives considerable improvements in heat transfer. Practical recommendations for this process have resulted from a study of heat distribution problems in a coke oven using an electrical analogue machine. In this, voltage is analogous to temperature, current to heat flow and electrical conductance to thermal conductance. The technique should be applicable to many other thermally complex problems. Initially, calculated values differed from observed temperature distributions, but it was possible to get good agreement by postulating heats of reaction during carbonisation. For three coals examined, a large endothermic heat of reaction was found between 450°C and 700°C. At 700°C the worst conditions of heat demand occurred, but above this the reactions were exothermic. This was experimentally confirmed.

An 8-in. diameter (100 lb./hr) continuous fluidised carboniser has been built. Work has concentrated on dust separation and tar condensation, which have proved the most difficult problems. One of the techniques reported to be used to overcome them by Gas Council workers is the use of hydrogen as the fluidising gas in a pressurised system. The N.C.B. has reported[10] a high yield of tar (at least 24 gallons/ton of coal charged) from a bed fluidised by steam at 650°C. The tars contained a disproportionate amount of high-boiling phenols and high-boiling neutral oils. They may prove to be rich sources of by-products and are being evaluated in a group of projects, including several sponsored at universities.

Another development has been continuous carbonisation of briquettes or small lumps of coal by heating with hot sand. A semi-technical plant has been built in which the briquettes pass downwards with a stream of preheated sand into a cylindrical chamber where the sand is separated from the briquettes, reheated and returned to the top of the system. This system is reported to carbonise briquettes in a quarter of the time required for the process in the indirectly heated narrow ovens which are normally used.

The N.C.B. work largely involves making briquettes from powdered coal. Three main lines of work on briquetting have been reported. Where the powdered coal is first thermally treated (by fluidised oxidation or devolatilisation), a newly-developed hot briquetting process at 300°C has proved to economise in heat and binder. Hot briquetting up to 440°C has proved possible, using as binder a compound of coal and pitch. Secondly, high-volatile coals, which normally burn giving off smoke, can make a smokeless carbonised briquette on the tonnage scale by using a "topped" tar as binder in place of pitch. Clustering of the briquettes is controlled by adding a modifier such as sodium silicate. Topping consists of removing the low-boiling-point fractions from the crude tar produced during the carbonisation, and the process is self-sufficient in binder. Finally, a new process has been patented for briquetting without binder, at moderate pressures with only moderately fine grinding. The basic idea is to cause relative movement of adjacent particles under load so that their surfaces are brought into more intimate contact by plastic deformation. Briquettes from low rank coals can be made with a compression strength measured across the diameter more than five times greater than that

of an ordinary briquette made at the same pressure. Carbonised at 700°C under optimum laboratory conditions, a strong briquette for furnace or foundry use may be produced. A 5 ton/hour automatic double table press has been designed for this work after experience with smaller machines.

Gasification

Probably the greatest prospects for synthesis arise from work on gasification. The main emphasis of work at the Fuel Research Station, Greenwich, has been on efficient utilisation of the more plentiful small size and lower quality coals. This includes exploring the possibility of gasifying finely-divided fuel by injecting it with air or oxygen through the tuyères of a gas producer containing large coke and working at a temperature sufficiently high for the ash to be removed as slag. Finely-divided fuel injected with the blast into the slagging zone should be gasified rapidly to provide the main source of gas, the large coke playing the part of a supplementary fuel with the function of enclosing a hot zone for the gasification of the fines. An alternative type of slagging gas producer is the cyclone in which fuel and air are tangentially injected at the periphery of a cyclone chamber, gas being discharged at the central outlet.

Improvements in the Fischer-Tropsch process may well come to be of key importance for the chemical development of coal. Workers at the Fuel Research Station now consider that the slurry technique in which the catalyst is suspended in molten wax through which the synthesis gas is bubbled, is likely to prove the most efficient and economical method of carrying out the synthesis. The effects of process variables have been investigated in small-scale reactors and in a 50-gallon-a-day pilot plant. It was hoped that the use of gamma radiation from a cobalt-60 source might enable the reaction to occur at lower temperatures and pressures. Preliminary results of this irradiation have shown no effect on the activity of a reduced cobalt-thoria-magnesia-kiese'guhr catalyst. More fundamental studies are now being made on the influence of the radiation in producing changes in the surfaces which could be of importance in modifying the behaviour of catalysts, such as measurements of the photo-electric emission.

Total gasification processes from coal—both at ordinary pressures and at pressures of 25 to 30 atmospheres—also form part of the programme of the Gas Council's Midlands Research Station. Two large pilot plants have been erected to provide data for designing an adaptation of the Lurgi process to British coals.

Tests are being made on operating the fuel bed at higher temperatures, on methane formation with fuel beds up to 20 ft deep and on incorporating a mechanical grate so that steadier conditions can be maintained in the fuel bed. In the second pilot-scale pressure gasifier the primary aim is to obtain experience of operating under a pressure of 75 psi with slagging conditions. The generator has been equipped with a slag quench chamber in which the slag is quenched by means of a water-cooled metal surface, self-lined with frozen slag to give some heat insulation, before it is withdrawn through a lock-hopper from the pressure system. Steam and oxygen are supplied in a volumetric ratio of 1:2. Gasification of coal in a fluidised bed is being studied in the laboratory using models to investigate the behaviour of fluidised beds when the coal is recirculated and the bed itself filled with special shapes. In addition, a full-scale experimental plant for hydrogenating petroleum oils to yield 7.5 m cu. ft of gas daily is being erected in the North-west in order ultimately to apply this process to hydrogenating low rank small coal by studying the chemical engineering problems common to both of the processes involved.

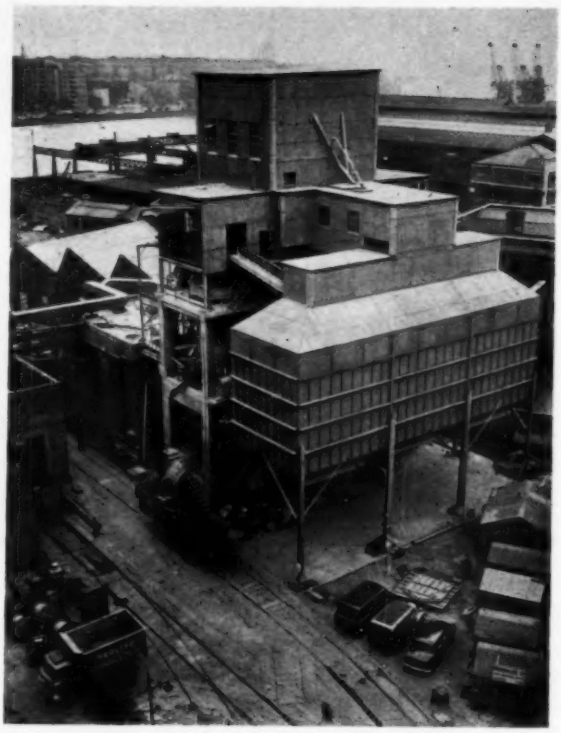

Fig. 6. Sinterlite plant at Battersea Power Station providing lightweight aggregate from fly ash.

Underground gasification has been investigated in many countries and British experience has shown that a gas of C.V. up to 100 Btu/cu. ft can be obtained when blowing air. Gas can now be produced at 4d a therm and converted into electricity, but it is estimated that by 1964 the cost should be down to 1.8d. The estimates were based on a 3-ft seam 400 ft deep, and would only be increased by some 15% if the depth were 1000 ft. In August, 1957, it was announced that the Coal Board is providing an underground gasification plant at Newman Spinney, in Derbyshire, to drive a 3750-kW turbo-generator set up by the Electricity Authority. It is hoped that the pilot power station will be operating by the end of 1958. There was no mention of chemical studies on the gas, although Russian popular accounts of their schemes have referred to combining the station with a chemical synthesis plant. A general review of British work was published in 1956 by the Ministry of Fuel and Power[13] and a further one in 1957 by C. A. Masterman[14] (given to the North of England Institute of Mining and Metallurgical Engineers).

Turbines and Fuel Cells

Special importance attaches to the work on turbines and this single field of combustion research is included because it offers the possibility of replacing an oil demand and providing another use for low-grade coal. The main major variations of the engine cycle are as follows:

(1) Open cycle with direct internal combustion of coal.

(2) Open cycle with direct internal combustion of producer gas.

(3) Open cycle with external combustion of coal.

(4) Closed cycle with external combustion of coal.

Plants of the later two types are fully or nearly complete. A turbine of type (2) has been manufactured, but the associated plant is still under development. The

POINTS OF VIEW

IN THE DEBATE in the House of Commons on the Annual Reports of the Gas and Electricity Industries, different points of view were expressed on the rate of progress in gas research, which is closely related to that of coal research.

PAYMASTER-GENERAL (MR. REGINALD MAUDLING)

"I should like to explain to the House some of the ways in which the industry is tackling this basic problem of producing gas from other raw materials. It is a good story. The efficiency of the gas industry is indicated by how much it is doing to try to develop the latest technological processes. As I have said, good-quality coking coal is becoming scarcer and dearer and we must look for other sources from which to produce gas. Clearly, the first source and the most valuable to exploit from the national point of view is lower-grade cheaper coal. A great deal of work is being done on that. There are two processes of complete gasification which the Gas Council has in mind. First, there is the so-called Lurgi process.... There is a second process, the hydrogenation process.... These two processes of complete gasification of low-grade coals are promising, but we need a good deal more experience of them, and in many cases the plants involved are very large and the processes might lead to considerable changes in the transmission and distribution of gas which would involve considerable capital expenditure."

MR. ROBENS

"My main criticism about the gas industry is that it has been so slow in its progress towards the complete gasification of our indigenous coal. This is scandalous, because the industry has been experimenting for years. I saw these experiments on complete gasification years ago in the laboratory. The Germans have been, for about thirty years, using the process to which the Paymaster-General has referred. It is really a little late in the day for the Gas Council now to say that it is beginning to build pilot plants. It should have done that a long time ago, and should now be much further ahead." *Hansard:* November 26, 1957.

simplest and most attractive of the cycles, number (1) above, burning powdered coal directly and passing the products of combustion through the turbine is the most difficult to develop due to the erosion and bonding of ash on to the turbine blades. Much experimental work has been done on combustion gas cleaning systems and on the physical and chemical aspects of bonding. It appears that the smallest ash particles of 5 micron size and downwards are the greatest offenders and means for their elimination are still being investigated. It is obvious that success in this field would greatly help to reduce imports.

Peat research, co-ordinated by the Scottish Peat Committee, has also included experimental development of an open-cycle and a closed-cycle turbine. A pilot-scale power station incorporating a John Brown 2000-Kw closed-cycle peat-burning gas turbine is now almost complete on the Altnabreac Moss in Caithness. On the open cycle, work was held up by the sintering of ash upon the blades. Both this and the development of nuclear power have made it likely that there will be no further work on the open-cycle engine.

Fuel cells offer the opportunity of converting chemical energy directly into electricity without the losses involved in using the heat engine. The ultimate efficiency attainable for the latter is some 40%, but fuel cells can be designed to give 65% conversion efficiency. Some work has been done using coal and a comprehensive paper has been presented by Bacon and Forrest.[12]

Ash Utilisation

Some 6.4 million tons of ash a year are currently produced at the electricity power stations, of which 2.8 million tons are fine dust from pulverised-fuel furnaces. The Electricity Authority and the Building Research Station are developing methods of sintering the ash to an aggregate and have also drawn up plans for the erection of experimental brickworks using fine ash mixed with a small proportion of clay. At Battersea Power Station the Sinterlite P.F. ash pelleting plant is now in operation yielding a light-weight aggregate suitable for use in making concrete with good insulating properties. In addition, a building block known as Thermalite is being successfully produced from fly ash and the Electricity Authority is itself proposing to establish an experimental brickworks at Hams Hall, near Birmingham, with an initial yearly production of 5 million bricks of up to 85% ash.

Processes are available for the extraction of germanium and gallium. The former has now been produced for several years on a commercial basis from producer gas flue dusts, but the Electricity Authority is also carrying out surveys in order to find if any of its ash contains the economic minimum of 0.1% germanium. So far no success has been achieved. Failure has also been reported by the Fuel Research Station after a study of what happens to germanium in coal during carbonisation; it was concluded that this process will not produce a waste product suitable for the economic recovery of germanium.

Conclusion

Coal is a heterogeneous material—both in terms of its organic matrix and even more in its dispersed mineral matter. This poses special problems for process developments which do not arise in working with pure substances. Yet there appear to be many lines of work in progress laying a sound basis for building the chemical future of coal and offering challenges to the chemical engineer. The main problem that remains is whether the scale and pace of current work are great enough.

Without committing him to the views expressed, the author wishes to thank Dr. D. G. Skinner of the National Coal Board for helpful discussions during the preparation of this article.

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AUTOMATIC MEASUREMENT OF QUALITY IN PROCESS PLANT

Summary of the recent Society of Instrument Technology Conference, Swansea

AUTOMATIC control has been applied in the process industries for many years and many commercial processes could not function efficiently without its aid—indeed, some could not function at all. The introduction of powerful new instrumental techniques, coupled with an advance in our knowledge of the fundamental mechanism of processes has led to a change in attitude to automatic control. In the past, control schemes have generally been devised to maintain constant certain basic parameters of a process —temperature, pressure or flow—in the hope that this would result in an end-product of unvarying quality. In many cases, long delays have resulted between the detection of variations in the quality of end-products and the correction of conditions on the plant. The economic benefits which could be obtained by carrying out analyses directly on the process stream have stimulated the development of a wide variety of instruments for this purpose. Many of these instruments have passed the experimental stage, and are now accepted as sufficiently reliable for plant use; many more are under development.

The complex nature of many of these instruments requires for their successful construction the co-operation of many specialists, and the Society of Instrument Technology is to be congratulated on having drawn many of them together at a recent conference on "The Automatic Measurement of Quality in Process Plant," held at University College, Swansea. Members were drawn from America, Germany, Holland, Norway and the U.S.S.R., so that the discussions provided a valuable international forum. (The full proceedings are to be published shortly by Butterworths Scientific Press.)

The seven formal sessions of the conference fell into two complementary groups; a number of papers were devoted to a review of the experience which had been gained with established instruments, while others explored the possible plant application of analytical techniques at present utilised only in the laboratory.

An apparently obvious first step in designing equipment for process analysis is that of taking the laboratory analytical process and attempting to mechanise it. In general, however, it is better to investigate methods of analysis better suited to plant operation. Nevertheless, there are times when this approach is satisfactory and the first session considered a number of such applications. Two papers considered automatic titration equipment. Here, chemical analysis is particularly suited to the determination of one component in a multi-component mixture of variable composition, since in many cases physical methods cannot be applied under these conditions. The difficulty of adapting laboratory methods to truly continuous operation was stressed in E. HODGSON's paper, which described an instrument for the determination of the crystallising point of batch samples.

Three papers presented in the following session described the manner in which this further step had been accomplished for calorimetric measurements on town's gas. This is a measurement of considerable importance to the gas industry which is bound by law to maintain certain standards of calorific value and purity in the gas supplied to consumers. Both here and elsewhere stress was laid on the difficulty of representative sampling.

A common problem in all branches of the process industries is the measurement of moisture. There was therefore particular interest in a paper by DR. K. M. GREENLAND describing an experimental instrument utilising a porous ceramic element, the electrical resistance of which is related to the humidity of the ambient air stream. This method may well have advantages over that using a hygroscopic chemical type of element.

Papers on the "Measurement of Some Mechanical Properties" included two of particular interest on viscosity measurement. This is a difficult determination under plant conditions, particularly for viscous liquids. In general, viscosity is measured in order to estimate some other property and those using viscometers tend to be more concerned with reproducibility than with accuracy. Here, again, representative sampling is of paramount importance.

Physical methods of analysis often provide a basis for continuous control—a trend reflected in papers devoted to the use of such diverse methods as dielectric constant measurement, vapour phrase chromatography and the various types of spectrometry. Of greater interest was the suggestion to use the technique of nuclear magnetic resonance for continuous analysis of process streams. The plant engineer who regards spectrometer techniques as still too difficult and complex for plant use would do well to ponder on the implications of the final paper of the day by DR. E. T. HALL, which described an X-ray fluorescence analyser, originally devised for the analysis of archæological specimens but now to be manufactured commercially for process use. These instruments are already in use experimentally, mostly in connection with coating thickness determinations on strip metal.

Computer Control

In an opening informal talk on the computer control of chemical processes PROF. ECKMAN recalled that the efficiency of a chemical plant is determined by both the quality of the product and the cost of production. Both are involved in optimising a process. He reported that a feasibility study of computer control in the case of the hydrogenation of cotton seed oil had led to a 23% reduction in batch processing time.

In the engineering design of instruments greater robustness was needed and more use should be made of first principles. The demands placed upon an instrument by a plant environment are different from those made by the laboratory, and the skills available for its maintenance are of a much lower standard. Furthermore, the development of analytical instruments must be accompanied by the development of the associated sampling systems. At present various process industries are expending a great deal of effort on the design of sampling systems to meet their particular needs, although their problems must, in many cases, share points of similarity. The Society of Instrument Technology provides a common meeting ground for both manufacturers and users. The Society may well act on the suggestion that it should attempt to co-ordinate research and development at present in progress and attempt to codify existing knowledge on sampling techniques.

STUFFING-BOXES FOR AGITATORS

by W. BAUMBACH*
Dipl., Ing.

Problems of shaft sealing in chemical vessels fitted with agitators present considerable difficulties in general mechanical engineering design. This article deals with some new designs of stuffing-boxes which have given good service

AN examination of a number of designs of stirred vessels showed that the simple form of stuffing-box was nearly always used. In this type, in which nearly the whole length of the stuffing-box protrudes into the vessel, a number of conditions must be fulfilled by the design.

(1) Safeguarding the lubrication conditions of the shaft, e.g., by means of a cooling jacket in the case of higher temperatures in the vessel.

(2) Protection against corrosion of all parts which come into contact with the product, e.g., by the use of alloy steels, metal shrouds, lead, rubber or enamel linings.

(3) For higher pressures, or when there are explosive or poisonous gases in the vessel, a large amount of sealing material is required at the stuffing-box. It is then necessary to use a double stuffing-box of a type shown in Fig. 1. In this case, accessibility for replacing the sealing rings is an important point.

(4) Protection of the agitator product from pollution through effluents from the gland box. This may be achieved by a compartment containing a thrower and, if desirable, an extraction pipe.

If all these requirements are satisfied, a complicated design is usually the result and one which is not suitable for continuous operating conditions. For this reason new designs of sealing devices were investigated.

Shaft Location and Seal Function

The first condition for the satisfactory operation of a stuffing-box is the smooth running of the agitator shaft. The choice and position of bearings are therefore important design problems. The lower shaft bearing is sometimes omitted and the bearing function transferred to the packing rings. This is only permissible if the degree of sealing required by the packing rings is very small. Very often the shaft is located by a bearing situated in the packing clamp ring. A good bearing surface between this ring and the seal-ring housing is therefore essential. This requirement leads logically to deep seal housings which are not easily accessible when gland rings have to be replaced.

The arrangement of a bearing between two sets of gland packings is frequently considered unsatisfactory due to the presence of a lubricant in the bearing and the possible contamination of the stirred aggregate. The best position for the bearing, from a designer's point of view, would be above the stuffing-box. However, even this has its disadvantages. One of these is the large space required above the gland nut for its withdrawal for renewal of packing rings, which enforces an increased distance between upper and lower shaft bearings.

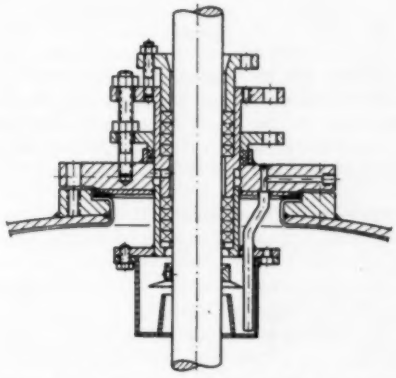

Fig. 1. Double-type stuffing-box for high pressures.

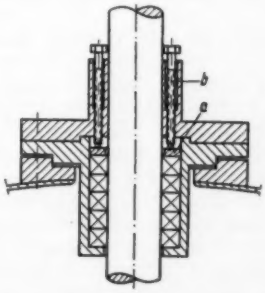

Fig. 2. Stuffing-box with integral bearings: (a) steel ring; (b) bolts. (Farbenfabrik Bayer A.G. Leverkusen.)

The consequences are increased deflections of the shaft as it rotates in the deflected state, aggravated by the bearing clearances. This causes the sealing rings gradually to lose their elasticity, open up and admit the agitated material, which in turn hardens and encrusts the packing rings. The sealing efficiency of the stuffing-box is therefore reduced and the gland requires continual tightening up. Moreover, the larger the distance between bearings, the

* Chemical Works Huls A. G. Marl.

The above is a condensed translation of an article published in *Chemie Ingenieur Technik*, 1957, **29**, 1, 44-46, prepared by A. Brand, A.M.I.Mech.E.

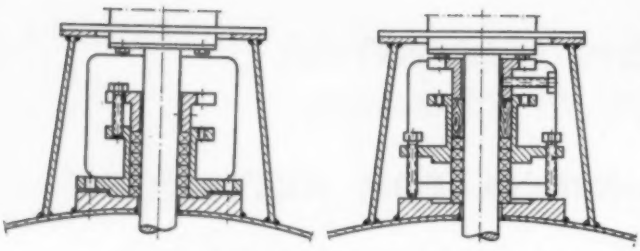

Fig. 3a (left). Stuffing-box mounted on boss welded to vessel. Fig. 3b. Method of replacing packings in stuffing-box of Fig. 2.

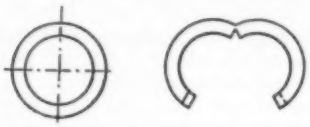

Fig. 4. Packing rings cut in readiness for assembling in gland.

more frequently will the packing rings have to be replaced. Further disadvantages to this bearing arrangement are the risk of damage to the shaft during the replacement of packing rings and the need for special ring-extraction tools for this time-consuming and difficult operation.

New Design Requirements

For a high degree of sealing the following points must be satisfied.

(1) The agitator shaft must run in faultless bearings with minimum bearing clearances.

(2) The stuffing-box must be placed as close as possible to the lower bearing, where the optimum design solution would be a combination of both elements into one unit.

(3) The gland packing space must be easily accessible.

(4) All parts of the sealing assembly must be well in line.

(5) A suitable packing material must be carefully selected.

The following examples show how these conditions for new designs of stuffing-boxes can be fulfilled:

Stuffing-box With Plain Bearing Attached

In the design shown in Fig. 2 the lower bearing of the shaft is rigidly attached to the stuffing-box housing. Compression of packing rings to seal off the shaft is carried out by screwing-down bolts b on to ring a. Accessibility to packing rings is good, since the bearing can easily be moved up the shaft when packing rings have to be replaced. Points 1 to 3 are here satisfied and this design can be recommended when plain bearings are used.

Stuffing-box With Outrigger Bearing

This design (see Fig. 3a) shows the stuffing-box outside the actual working container of the mixing apparatus. It is therefore little influenced by the temperature in the interior of the container and makes protection from corrosion and cooling unnecessary. The first operation to renew the packing rings is to move the packing-clamp-ring upwards to the underside of the bearing and to lock it in this position. A wooden distance piece is then inserted as shown in Fig. 3b. The nuts are then removed from the studs which hold the gland housing to the container, and by means of extraction bolts the gland housing is lifted upwards to free the packing rings. A complete cut on one side of the packing ring and an incision diametrically opposite, as shown on Fig. 4, facilitates removal and renewal of the rings. A combination of this design with the type shown in Fig. 2 offers advantages which are worthy of consideration.

Extended Stuffing-box

Demands for a high degree of shaft sealing have led to the design shown in Fig. 5a. The packing rings are contained in a sleeve (b) which is pulled upwards against the lower coverplate of the outrigger bearing. The packing rings are compressed between the hub of the bearing coverplate and the collar of a sleeve (a), which could be reduced to a simple ring. The stuffing-box housing is itself sealed off against the cover flange of the container. The seal assembly shown in Fig. 5a may be replaced by a simple "O" ring, since it is stationary.

When the packing rings of the main stuffing-box have to be replaced, sleeve b is lowered until all rings are completely accessible for removal.

The following must also be considered. The stuffing-box will behave like a piston if there are high pressures inside the container. It will tend to move outwards, but is prevented from doing so by the packing rings. This means that the packing rings could be subjected to a higher pressure than that required for sealing purposes. To prevent this, the housing b is held by screws (not shown in Figs. 5a and 5b) against the bearing cover. When it is required to increase the pressure on the packing rings, these screws will have to be released before the bolts pulling the housing b upward can be adjusted. For the same reason, i.e., the pressure inside the container, it is also necessary to fix sleeve a by means of a shear pin to the housing b. At low pressures, e.g., at 3 atm., this may be omitted.

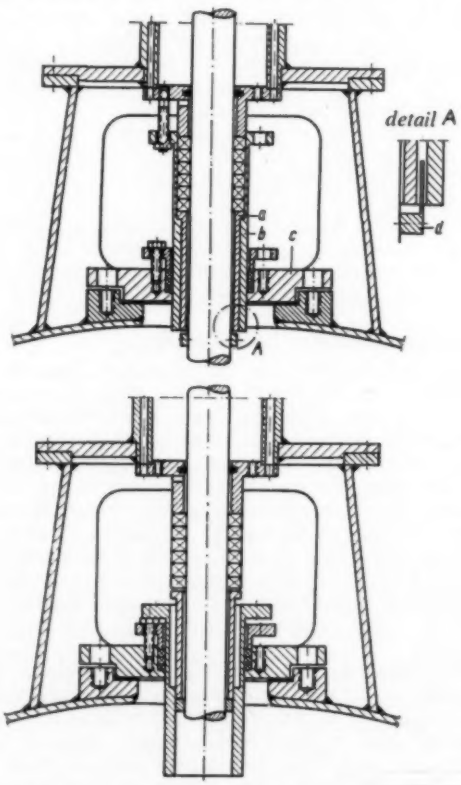

Fig. 5a (top). extended stuffing-box: (a) sleeve with collar; (b) stuffing-box housing; (c) flange; and (d) dust collector. Fig. 5b. Method of renewing packing.

TRENDS IN TONNAGE OXYGEN PLANTS

A summary, including the discussion, of two papers given to the recent Low Temperature Conference, on special design problems associated with air separation plants and recent developments in such plants

BOTH the paper given by P. M. Schuftan and A. G. Mackie[1] (B.O.C.) and that given by M. A. Dubs[2] of the Linde Co. (Division of Union Carbide Corporation, U.S.A.) described plants that are able to cope with a variable demand of product without loss of efficiency. In each case, however, a different approach was made to this problem of flexibility.

The Rescol Air Process

Since labour costs are relatively unimportant in large air-separation plants, the designer aims at the best blend of capital and power costs in such plants. Another aim will be a plant able to operate efficiently despite a fluctuating demand for its main product. One way of realising both these objectives is embodied in the latest version of the B.O.C. Rescol process. This later development, unlike its predecessor, uses air reflux instead of nitrogen; it requires a single compressor, whereas the earlier plant required two.

The plant produces some L.O. as well as its main gaseous product. By altering the G.O.:L.O. ratio, it is possible to meet a variable demand for gaseous oxygen at the expense of total output, for the ratio above can be varied over a wide range. The liquid oxygen produced can be stored and evaporated when the demand is high or when the plant is shut down.

The important features of the plant are shown in Fig. 1. Air is fed to the plant in two main streams, one at 26 psig (L.P.) and the other at 56 psig (I.P.). In addition, a small fraction of the I.P. air is withdrawn after passing through the direct coolers (Fig. 1) for the purpose of balancing the regenerators. This portion of air (H.P.) is treated to remove CO_2 and compressed to 3500 psig maximum.

The "cold" for producing L.O. is derived from all three air streams, but when the L.O. fraction has to be large the main source of cold is the I.P. stream which is expanded in one or two turbines. When the demand for G.O. falls one or both I.P. turbines (15) are put on full or part load and the exhaust is passed into the waste nitrogen line.

The more L.O. is produced, the greater is the quantity of nitrogen required for balancing the regenerators; hence

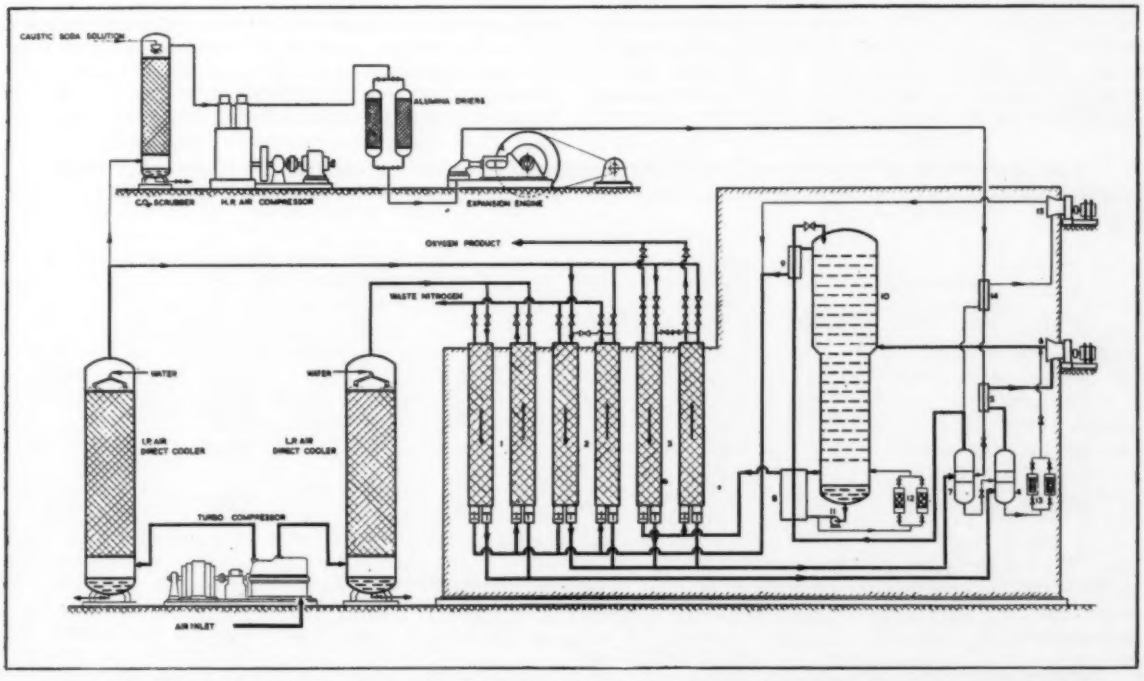

Fig. 1. The Rescol H Process, a plant designed for a variable gaseous oxygen demand. (1) *regenerators for L.P. air;* (2) *regenerators for I.P. air;* (3) *I.P. air-G.O. regenerators* (4) *L.P. equaliser;* (5) *preheater for air prior to expansion;* (6) *L.P. turbine;* (7) *I.P. equaliser;* (8) *condenser-reboiler;* (9) *exchanger;* (10) *rectification column;* (11) *L.O. pump;* (12) *adsorbers for impurities;* (13) *filters;* (14) *preheater for I.P. turbine;* (15) *I.P. turbine.*

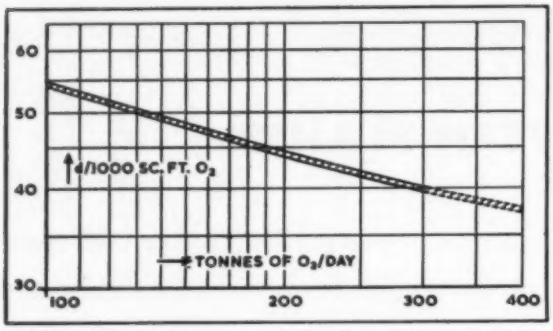

Fig. 2. Operating costs of the Rescol Process with 7% liquid production.

the capacities of the compressor and expander can be varied over a wide range. Under conditions of low G.O. demand, when the I.P. turbines are working the throughput of the H.P. compressor and expander is increased. At the same time the cycle of the regenerators may also be increased.

Flexibility is a feature of the rectification stage also. In the double column of more conventional plants the reflux ratios in either section can only be varied between very narrow limits. Introducing precooled air (known as the Lachmann air) into the upper coloumn goes some way towards removing this shortcoming, but it has the disadvantage of making rectification and refrigeration interdependent. The single column of the Rescol plant does not suffer from this disadvantage and it can, therefore, be operated more reversibly. The operating pressure can be changed according to the cold required, and the yield and purity of the oxygen are determined independently by the fraction of I.P. air used for rectification.

The low operating pressures make for very low temperatures in the regenerators. For example, the L.P. air leaves them at about −181°C and the I.P. air leaves regenerators (2) and (3) at −173°C. A very pure air supply is thus obtained, so much so that the CO_2 and C_2H_2 concentrations in the air leaving the regenerators is 10% of those encountered at the exits of regenerators of double-column plants. Rectification in the Rescol process is therefore inherently more safe than with plants operating at higher pressures. A final purification is achieved in the equalisers (7) and (4) for the I.P. and L.P. streams respectively. The latter stream, for example, has a temperature gradient during each regenerator cycle and the equaliser, by scrubbing this air stream with liquid air, reduces its temperature to the dew-point. Traces of impurities are also removed by this process.

Expansion of the L.P. air through turbine (6) provides some of the cold requirement, and preheater (5) ensures that liquefaction does not occur in the turbine.

Impurities which penetrate as far as the rectification column such as C_2H_2, O_3, oxides of nitrogen, must not, in the interests of safety, be allowed to accumulate. The method for their removal adopted at this plant is ingenious. It consists of circulating L.O. from the column sump through adsorbers, with the result that the C_2H_2 concentration is kept lower than 0.25 vpm.

Plant Design Features

The turbo-compressor is a five-stage integral machine with the L.P. taken off at the third stage. Isothermal efficiency is 67%. The ratio of I.P. to L.P. air determines the rectification performance and careful control of the two air streams is therefore essential. An Askainia controller is used for this purpose.

The H.P. compressor is a four-stage reciprocator with a double-acting first stage, one cylinder of which can be cut out to give variable capacity.

The regenerators employ stone packing and have stainless-steel shells. In the case of the pure oxygen regenerators contamination at change-overs has to be avoided. Duplicate change-over valves in series at both warm and cold ends are used for this purpose and at the warm end vents are fitted between each pair of valves. Some oxygen (3 to 4% when 99.5% oxygen is to be produced) is lost during the change-over but recovery of this loss may be possible. Of considerable interest are the equalisers. These vessels have two plates, the lower plate of each being of the bubble-cap variety and the upper one of the sieve tray type. In each case liquid air feed is introduced on to the lower tray and vapour from the regenerators enters below this tray. Liquid is returned to the equaliser bottom by means of a single central downcomer. Initial difficulties caused through CO_2 deposits on the expansion valves were

TABLE 1.—Physical Properties at Normal Temperatures of Aluminium Alloys for Low-temperature Work

Alloy				ASME code design strength	Tensile strength (Code minimum)	Yield strength 0·2% offset (Code minimum)	Elongation (Typical)	Shear strength (Typical)	
Commercial									
ASTM	Old	New	Temper	(lb./sq. in.)	(lb./sq. in.)	(lb./sq. in.)	(%)	(lb./sq. in.)	Use
Commonly used alloys :									
M1A	3S	3003	0	3 350	14 000	5 000	23	9 000	Welded properties
			H14	5 000	20 000	17 000	6	12 000	Sheet and plate.
			H112	3 600	14 500	6 000	8	10 000	Pipe.
GS11A	61S	6061	T6	10 500	42 000	35 000	18	20 000	Structural.
			T6	6 000	24 000	—	—	—	Welded properties.
GR40A	A54S	5154	0	7 350	30 000	11 000	18	18 000	Sheet and plate.

Nominal Composition

Alloy			Alloying elements (%) (Aluminium and normal impurities constitute remainder)					
Commercial								
ASTM	Old	New	Copper	Silicon	Manganese	Magnesium	Chromium	Titanium
Commonly used alloys :								
M1A	3S	3003	—	—	1·2	—	—	—
GS11A	61S	6061	0·25	0·6	—	1·0	0·25	—
GR40A	A54S	5154	—	—	—	3·5	0·25	0·15

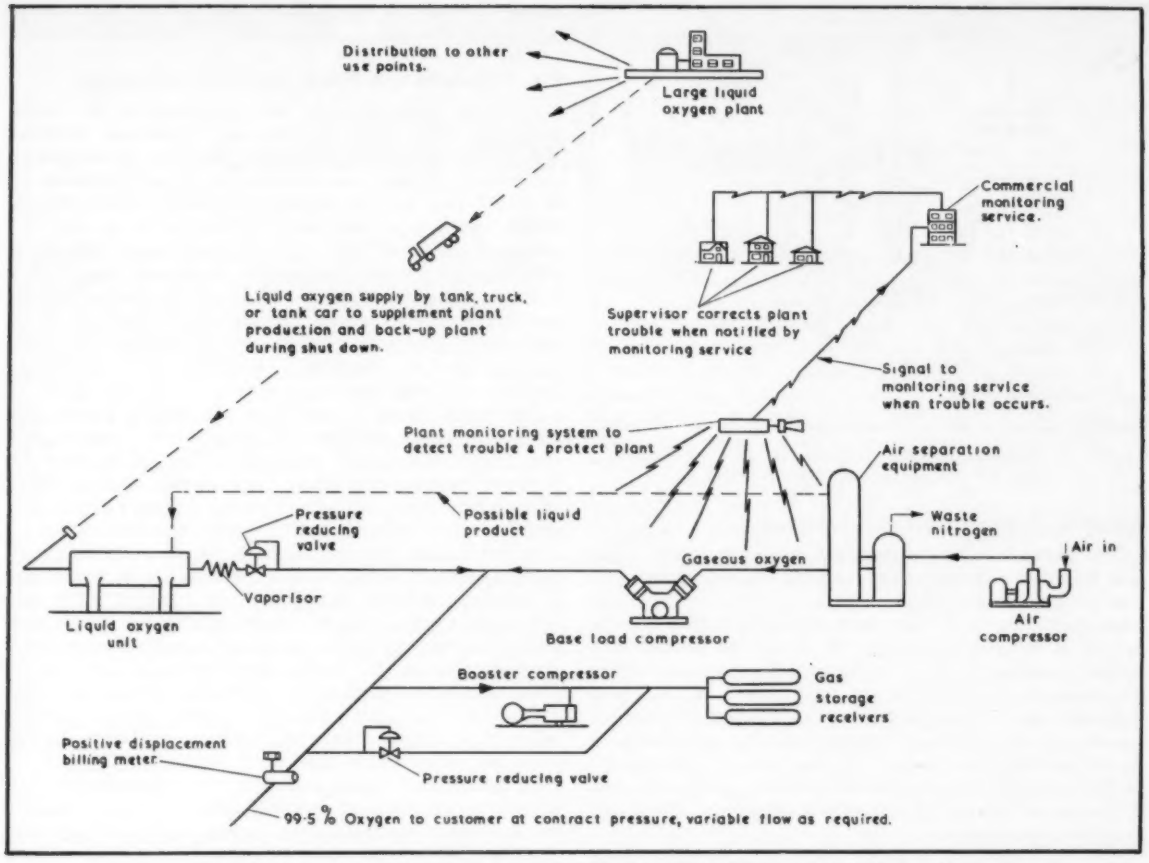
Distribution to other use points.
Large liquid oxygen plant
Commercial monitoring service.
Liquid oxygen supply by tank, truck, or tank car to supplement plant production and back-up plant during shut down.
Supervisor corrects plant trouble when notified by monitoring service
Signal to monitoring service when trouble occurs.
Plant monitoring system to detect trouble & protect plant
Air separation equipment
Pressure reducing valve
Possible liquid product
Waste nitrogen
Air in
Gaseous oxygen
Vaporisor
Liquid oxygen unit
Base load compressor
Air compressor
Booster compressor
Gas storage receivers
Positive displacement billing meter
Pressure reducing valve
99·5 % Oxygen to customer at contract pressure, variable flow as required.

Fig. 3. An automated gaseous oxygen plant designed for a variable demand.

overcome by filling the filter cartridges with silica gel.

To meet the variable rectification conditions of an L.O.-G.O. plant, the lower section of a column has been designed for higher-than-normal vapour velocity and the sieve tray spacing, to compensate for greater entrainment, is greater than usual. Nevertheless, the height of the cold box is less than that of a double column. The column has been designed to produce a waste nitrogen of 8% O_2, a pure nitrogen of 99.5% and an oxygen purity of 99.65% has been achieved.

The design of the other plant components, such as expanders, is also outlined in this paper. The low-pressure turbine, for example, is a radial inflow machine with an adiabatic enthalpy drop efficiency of about 80%. It runs at 8500 rpm (below the critical speed) and in common with the other expansion machines of this plant it is loaded with an induction generator which feeds power back to the L.T. mains. The expanders contribute 4% of the total power required by the process and more for maximum L.O. production.

The importance of a high standard of thermal insulation of the plant was also stressed. A 10% reduction in losses caused by heat inleakage would amount in the case of a 100-ton-a-day plant to 1 ton of product. The Rescol plant, by virtue of its layout, offers greater scope for improvements in this direction than other tonnage oxygen plants.

Operating data are given for a 99.5% purity product. Thus for a 200-metric-ton-a-day plant producing 186 tonnes of G.O. and 14 tons of L.O. the specific pure consumption is 0.525 kwh/sm³. The operating costs given in Fig. 2 are based upon the figures given below.

Power	1.0d. a kWh
Cooling water make-up	1s. 6d. per 1000 gallons
Caustic soda ...	£42 a ton
Labour	Two operators a shift and one man on day shift
Maintenance ...	2½% of capital
Maintenance labour	40% of maintenance charge
Overheads	70% of labour costs for operation and maintenance
Depreciation ...	15 years
Return on capital ...	15%
Production time ...	8400 hours a year

In discussion, A. M. Clark observed that many of the developments which had taken place in the steel industry had been made possible by the low cost of tonnage oxygen which at £47 a ton for a 200-ton-a-day plant was the lowest-priced high-purity industrial commodity available today. Dealing with the directions in which further economies might be made, he reckoned that the cost of labour represented 4% of the total cost of production, power 30% and capital charges 40%. These figures were not claimed to be highly exact, but they did show that in the U.K. it was not worth saving labour at the expense of any considerable increase in capital cost. A 10% improvement in thermodynamic efficiency, which would mean a considerable technical advance, would only reduce the cost of oxygen by 3%. The most important savings would therefore be made by reducing capital costs, and an important factor here was efficient utilisation, which was difficult to achieve in the face of a variable demand. The Rescol plant obtained this by means of flexibility derived from the combined liquid and gas production.

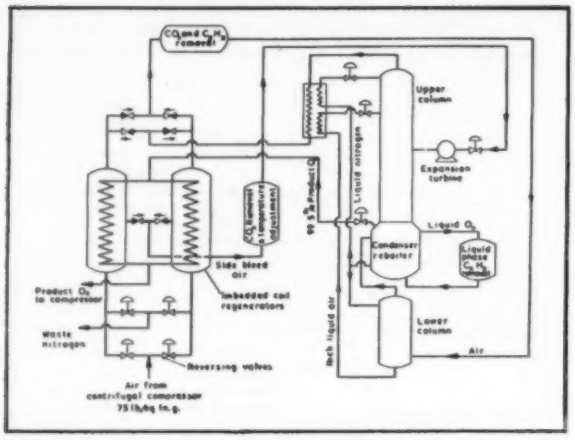

Fig. 4. Simple process diagram of air separation unit, 80 million cu. ft/month oxygen.

Another Approach to Full Utilisation

Mr. Dubs described a plant which was basically a gas unit linked to a liquid oxygen storage system (see Fig. 3). The oxygen is compressed to pipeline pressure and if the consumers' demand is lower than plant output, then gaseous oxygen is pumped to storage. If demand is greater than output, gaseous oxygen is withdrawn from storage. When the demand is too great to be satisfied in this way vaporised oxygen from liquid storage is added to the main oxygen stream. The liquid oxygen may be obtained as a liquid fraction from the plant at site or it may be brought in from an L.O. plant, whichever is the more economic. An important feature of this plant is that it is unattended and fully automated.

The cycle devised to satisfy these conditions is shown in Fig. 4. To maintain self-cleaning in the plant, the regenerators are unbalanced and the air withdrawn at −100°C is treated to remove impurities by adsorption or by further lowering of the temperature. This air is mixed with clean cold air from the main stream, so that after expansion it is close to saturation. Synthetic zeolites are used at the reboiler to bring about complete removal of acetylene and hydrocarbon.

The distillation columns use sieve trays and the heat exchangers are of the extended-surface type. The regenerators use a cheap packing with coils embedded in them.

The standard of instrumentation and automatic process control equipment must be of a high order in order to allow for a shut-down time of 2% of the total running time. The equipment used must be simple mechanically and pneumatic instruments are preferable. The instrument air supply is taken from the process stream at a point where it is oil free (at −150°F); a clean and reliable supply of air is thereby obtained.

Among the important variables controlled are the amount of side bleed from the regenerators and the turbine exhaust temperature which has to be held close to saturation. Process monitors look after product purity, cooling water pressure, compressor oil pressure and the various pressures in the separation plant. The monitoring system does not rely upon controllers with alarm contacts for separate controllers operated by the monitoring system are invariably used

Evidently something new in the way of insulation is used in these plants. This is an expanded perlite with thermal conductivity of 0.018 Btu/h ft² °F ft and specific heat 0.2 Btu/lb. By its nature, this insulation is readily removed from lagging casings to allow the plant to be inspected and maintenance to be carried out. It will pack closely round the equipment and reduce considerably convection currents.

Plant Details and Materials of Construction

Packaged plant received brief mention in Mr. Dubs' paper, but some interesting data on compression machines were given. Linde's experience is that the centrifugal air compressor is the most economical for air pressures of 60 to 100 psig and for capacities in excess of 600,000 cfh. Water injection at each wheel gives values of adiabatic efficiency of 70 to 75% for such duties. For deposits of 400,000 cfh or less, reciprocating compressors are used.

Plants turning out 45 × 10^6 cu. ft a month will use radial expansion turbines with an inlet pressure of 75 psig and a discharge pressure of 5 psig with efficiencies as high as 83%. Oxygen is compressed by centrifugal machines in large and reciprocators in smaller plants.

For materials of construction, in oxygen plants, aluminium and its alloys are used extensively. Thus an alloy with 3.5% Mg, 0.25% Cr and 0.15% Ti is used for pressure vessels except where cyclic conditions or reversals of pressure occur. This is because the strength of aluminium alloys falls off rapidly after about 1000 cycles.

In fabricating a vessel the weld detail is especially important. Unfortunately, with aluminium good penetration is normally difficult to obtain. Butt welding, even with ¼-in. plate thickness, is seldom successful. For this reason thin plate backing strips should be employed and above these thicknesses "V" welds should be used.

Reference was made to an interesting nickel-steel alloy containing 9% nickel. This has a 20% greater strength than 18-8 stainless steels and costs a third less. It has, however, to be stress relieved at 1025 to 1075°F.

In discussion on this paper, Mr. Clark noted that flexibility of operation and complete utilisation were obtained in this plant by integrating liquid oxygen supply and storage with a G.O. plant. The design also showed how labour could be eliminated by automatic control; e.g., the labour of two men a shift plus one day man were dispensed with. Dr. M. Pearce commented that with overheads this ought to save something like £10,000 a year, which might well be about the cost of the control equipment used in the plant described.

Doubts were expressed as to whether labour costs (3 to 4% of the total) were really worth much attention. In answer to this point, the author gave the impression that the main aim of automation was process improvement and the economies effected meant that the control equipment was, in fact, paid for within a very short period. The size of plants which were unattended had outputs of 7 × 10^6 cu. ft a month and 20 × 10^6 cu. ft a month. Of the larger plants, the 48 × 10^6 cu. ft a month were attended one shift a day. Their 200-ton-a-day plant when completed would be attended two shifts a day. However, with the large tonnage plants (producing 95% oxygen) which were very stable automation would not be attempted.

The stability of large tonnage plants was stressed by Dr. Wucherer, who stated that the most important components to have controlled automatically were the regenerators, which in the case of Mr. Dubs' plant were balanced through the mid-point temperature.

In answer to a question on the merits of electronic instruments, Mr. Dubs stated that although these were free from the difficulties arising from freezing, pneumatic instruments were preferred, for they were cheaper and, if provided with an excellent-quality air, were more reliable.

REFERENCES

[1] The Rescol Process, by P. M. Schuftan and A. G. Mackie.

[2] Recent Developments in Industrial Oxygen Production, by M. A. Dubs.

Both papers presented to the symposium on "Recent Developments in Industrial Low Temperature Gas Separation" held jointly by the Institution of Chemical Engineers and the Low Temperature Group of the Physical Society, London, 1957.

AMERICAN LETTER

Contract Plant Maintenance

PLANT maintenance has been called the handmaid of production, and to managements maintenance is merely a secondary problem that somehow seems to get worse every day. These attitudes and the use of terms such as "non-productive labour" on the part of production men do not help in any way. Maintenance problems can only be solved by regarding them as items of major concern, which completely justify top-rate specialists, expert administration and full consideration when shaping plant policies. The gradual automation of many industries is emphasising such fundamentals, particularly in the chemical field.

As is well known, a top-flight engineer may not, *ipso facto*, prove to be an expert administrator as well, especially in a field such as plant engineering, which does not readily lend itself to complex planning and low-cost operation. The simple method of employing swollen maintenance staffs in order to cope with possible emergencies or an ageing plant is no real solution, since it creates an indolent maintenance department, as well as inflating total productions costs. A company with an efficient, well-run plant engineering section may count itself fortunate, for able administrators are frequently harder to find than expert craftsmen. The situation becomes even more serious in the case of multi-million dollar plants, which are being built in increasing numbers. What, then, can management do about harassing maintenance problems?

One promising solution may lie in contract maintenance, which is being operated successfully both on a large and a medium scale in Canada and the U.S.A. and could probably be applied to many European plants, now and in the future. As the name implies, contract entails the undertaking of plant maintenance by a specialist firm of contractors, which to some people will instantly sound like an impossible idea. However, this principle has been widely applied for some time to specialist functions such as instrument, boiler and structural maintenance and the results have usually been very satisfactory. As currently practised in the U.S.A. and Canada, contract maintenance services may be said to be of four general types, and are, namely:

(1) The provision of a labour force only, for general and/or peak work.

(2) Assistance with plant turn-arounds.

(3) A permanent, supplemental labour force.

(4) Overall maintenance administration and execution.

Certain advantages common to all four types of service are claimed. The chief advantage is said to lie in a flexible payroll which can be extended, selected or reduced according to actual, and not imagined or eventual requirements. Furthermore, this can be done without creating the bitterness which would probably arise if adjustments to a rooted maintenance force were attempted. Another advantage is said to lie in the employment by the contractor of first-rate supervisors and mechanics, who generally increase their skill and versatility by the very nature of contract work. Another important feature is that plant management has more freedom to concentrate on production. In addition, overall fringe benefits, insurances and payroll overheads can be reduced and advantageous relations with trade unions may also arise.

The first type of contract is being successfully employed as an aid to peak labour requirements and creates fewer problems than temporary additions to the established maintenance payroll. However, since the contractor's labour force will probably have different wage rates and conditions of employment, some anomalies may develop, unless the local labour force is made to realise that the more nomadic life of a contract worker and a possibly greater experience usually commands a higher rate of pay. A further disadvantage may arise if a contractor's crew works under indifferent local supervision. Therefore, it is preferable as a rule to hire a contractor's crew complete with supervision if possible, and employ the squad on specific jobs, rather than let the contractor's men merely diffuse into the maintenance force of the plant.

Plant Shut-down

The second type of contract is for plant shut-down or turn-around. It has several advantages and sometimes can be on a fixed-cost basis. Payroll problems for the plant owner are simplified, screened, first-class tradesmen may be employed and integration with the plant's own maintenance staff presents fewer difficulties. Usually, the plant owner is responsible for the planning and scheduling of the programme. The third type of contract, whereby a limited, but permanent contractor's force is maintained at a plant, has two distinct advantages. Peak requirements are met by adding to the contractor's force only and at the same time the problem of quickly integrating a temporary labour force with the plant maintenance team is reduced, particularly if the contractor retains one or two good craft supervisors at the plant. Again, trade-union relations are apt to be smoother under this type of contract, than if direct, short-term hiring were used. Sometimes, a competitive spirit may exist between the two teams, with advantage.

The fourth type of maintenance service, covering overall administration and execution, is said to give by far the greatest yield and savings to the plant owner, who only need employ sufficient maintenance personnel to co-ordinate the plant production staff with the contractor's site executives. Under a complete maintenance contract, a qualified engineering staff is supplied, together with an experienced planning and scheduling team, flexible staff and field supervision, together with a flexible force of skilled craftsmen and possibly many of the special tools, rigging and equipment needed as well. However, the main emphasis is on flexibility, plus skilled administration and planning; it has also been stated that the contractor's craftsmen may prove to be quicker and superior to the average plant maintenance force. The largest contract maintenance scheme in operation at the present time is believed to be at the recently-built refinery of the Tidewater Oil Co. at Delaware, U.S.A. This project cost about $200 million and has a total daily capacity of some 130,000 barrels per day. The refinery has been on stream for about one year only, but the benefits of having a flexible maintenance force readily adjustable in size (from 400 to 200 men) have already been evident, and the refinery is not likely to be faced with a swollen maintenance payroll when plant oprations reach normal.

STATISTICAL TESTS

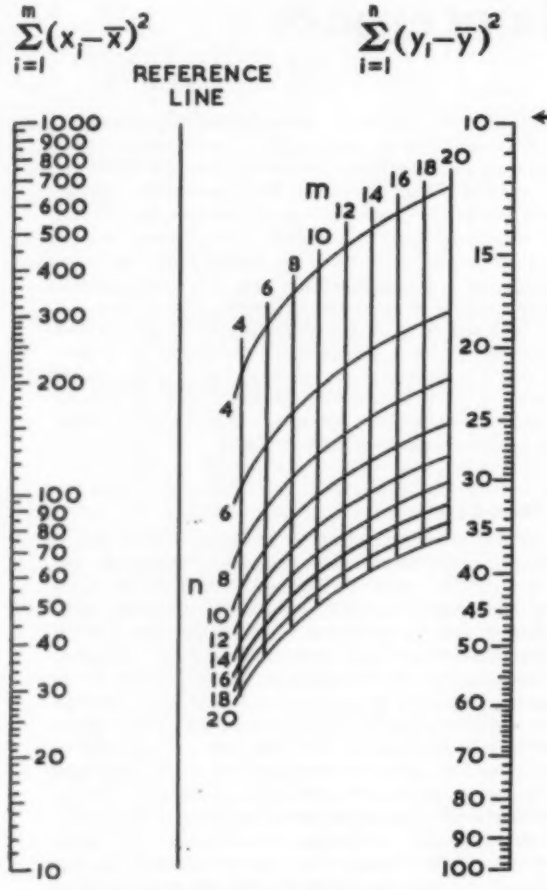

FIG. 1: COMPARISON OF TWO VARIANCES
(two-sided F-test)

Suppose we have m observations of x and n observations of y and the x observations seem to be the more variable. We ask, "is the x population really more variable, i.e., has it a greater spread, than the y population?"

First calculate $\sum_{i=1}^{m}(x_i-\bar{x})^2$ and $\sum_{i=1}^{n}(y_i-\bar{y})^2$, where $\bar{x}$ and $\bar{y}$ are the means of the respective observations. Join these points on Fig. 1, and note where the join meets the reference line. If this meet is above (vertically higher than) the point given on the net by the appropriate m and n, accept (at the 5% level) that the x population is the more variable.

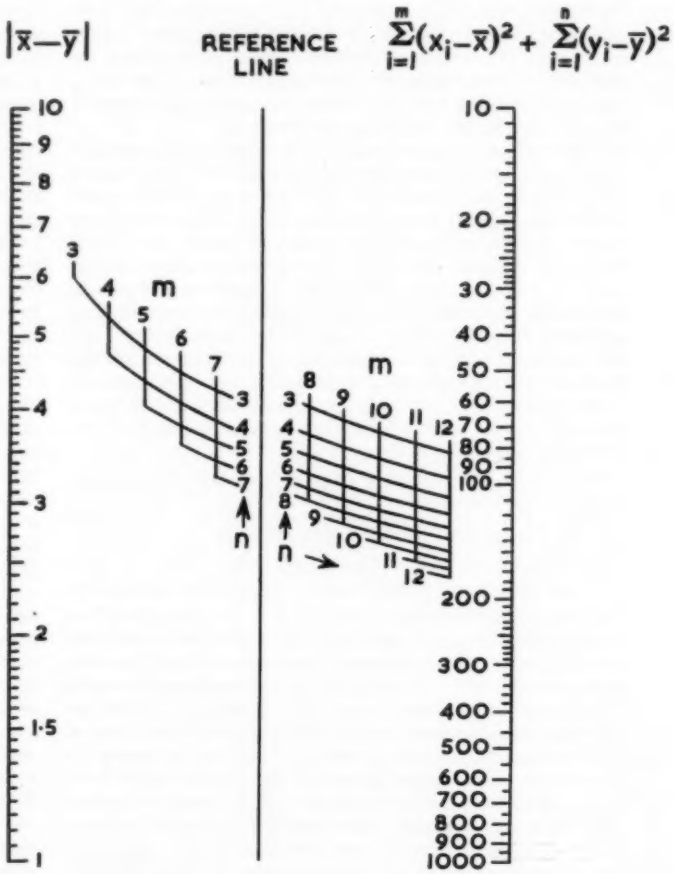

FIG. 2: COMPARISON OF TWO MEANS
(two-sided t-test)

Suppose we have m observations of x and n observations of y and we ask, "Are the means of the x and y populations really different?"

First calculate $\bar{x}-\bar{y}$, the difference (without regard to sign) of the observed means, and $\sum_{i=1}^{m}(x_i-\bar{x})^2+\sum_{i=1}^{n}(y_i-\bar{y})^2$. Join these points on the nomogram and note where the join meets the reference line. If this meet is above (vertically higher than) the point given on the net by the appropriate m and n, accept (at the 5% level) that the means of the two populations are really different.

Example: Suppose $\bar{x}$ is 21·6, $\bar{y}$ is 24·5, $\sum_{i=1}^{7}(x_i-\bar{x})^2$ is 29·7 and $\sum_{i=1}^{10}(y_i-\bar{y})^2$ is 30.5.

In Fig. 1 the meet of 29.7 and 30.5 is well below the point (7, 10) on the net, and we concluded that there is nothing to show the population variances are different.

In Fig. 2 the meet of 2.9 and 60.2 is distinctly above the point (7, 10) on the net, and we conclude there is a real difference between the population means.

These nomograms are more thoroughly explained in *Applied Statistics*, **3**, 33-45 (1954), and are reproduced by kind permission of Dr. S. R. Broadbent, *Applied Statistics* and Oliver & Boyd Ltd.

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attention to detail

Skill, experience and attention to detail during the design and manufacturing stages of HWP/Fluor Counterflo Cooling Towers, ensure that cooling can be guaranteed between prescribed limits, and that the Towers will function with the utmost efficiency and minimum attention for long periods

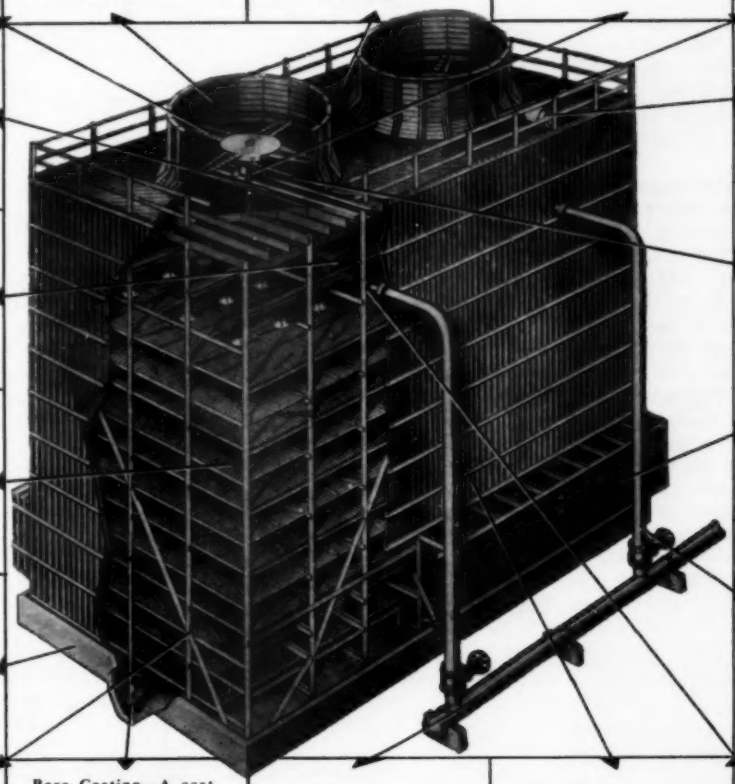
Fan Assembly—A high efficiency, low speed, axial type, cooling tower air prime mover.

Fan Stack—Specially designed for trouble-free, vibrationless operation. Fabricated of seasoned redwood. Internal annular ring ensures maximum exhaust velocities.

Fan Deck—Diagonal decking, blocking and stress strips form a structural diaphragm which distributes live loads—wind, vibration—uniformly to all bracing.

Speed Reducer—A device for reducing fan driver speed to fan operating speed. May be single or double reduction gear or hydraulic motor.

Vibration Cut-Out Switch—In case of excessive vibration of mechanical assembly, automatically shuts down fan driver.



Support for Driver and Speed Reducer—Structural unit support for driver and speed reducer.

Fan Driver—A prime mover for fan service that may be an electric motor, gas turbine, steam turbine, or hydraulic motor.

Drift Eliminators—A multi-pass baffle section constructed to minimize the entrained water in exit air stream.

Drive Shaft—Floating shaft and flexible coupling assembly for transmitting power from driver to gearbox.

Tower Filling—Grid Decks or filling to provide maximum and continuous water break-up with a minimum of obstruction to flow of cooling air.

Louvres—Set three feet out from side, yet require no greater basin dimensions. Air is drawn into tower with less pressure drop. Icing problem formerly associated with louvres adjacent to tower columns eliminated.

Basin—This collects the tower water and provides structural support for tower.

Riser—That vertical connector pipe between the manifold and cooling tower header.

Water Distribution System—Completely non-corrosive . . . header and laterals of redwood stave construction banded with stainless steel . . . nozzles of porcelain (and stainless steel) or plastic. Headers and laterals are provided with cleanout valves and plugs for flushing during tower operation.

Structural Framing—Redwood columns, braces, and chords, through bolted, utilizing connector plates.

Base Casting—A cast footing provided to ensure a uniform and solid connection between the tower columns and the basin pads.

Manifold Header—A hot water pipe manifold distributing water to individual risers and cells.

Sheathing—A tower sheathing designed for architectural beauty and positive elimination of leaks.

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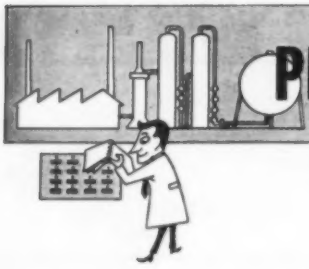
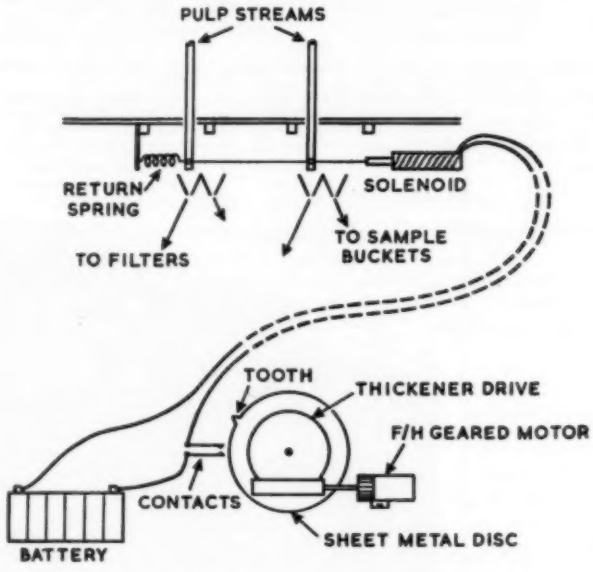


PROCESS ENGINEER'S NOTEBOOK

Automatic Sampler

DURING A PROLONGED pilot-plant investigation of a hydro-metallurgical problem it was found necessary to take an ever-increasing number of samples. Since only one operator was on duty each shift, economical ways of taking samples automatically were devised to reduce the load on the operator. One method is shown opposite.

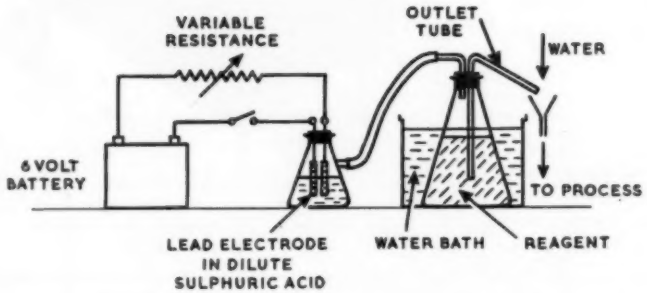
In this case two pulp streams were flowing by gravity in rubber hosing through a floor and on to a vacuum filter where the filter cake was periodically removed. These pulp streams were sampled by hand at regular intervals and a method of automatically diverting the streams was thought desirable. The installation consisted of a fractional-horse-power geared motor driving a spare thickener worm-drive gearing. A 16-gauge sheet-metal disc was fixed to the output shaft and a final output speed of one revolution every 57 minutes was then obtained. A Paxolin tooth was attached to the periphery of the disc and a pair of contacts placed in such a position that, on passing, the tooth closed the contacts for 20 to 30 seconds. The contacts in turn operated a home-made solenoid actuated by a 12-volt multi-compartment industrial battery and designed to give a maximum pull of 3 to 4 lb. per sq. in. Wire connected the two rubber hoses to the plunger and a spring ensured the return of both the solenoid plunger and hosing when the electrical contacts were broken.



An Electrolytic Reagent Feeder

AN OCCASION AROSE when very low flow-rates were required to add a water-immiscible frother to a metallurgical pulp to aid the subsequent flotation process. Available conventional reagent feeders were unable to feed accurately at the rates of 2 to 4 ml an hour required, with the result that an electrolytic feeder was built.

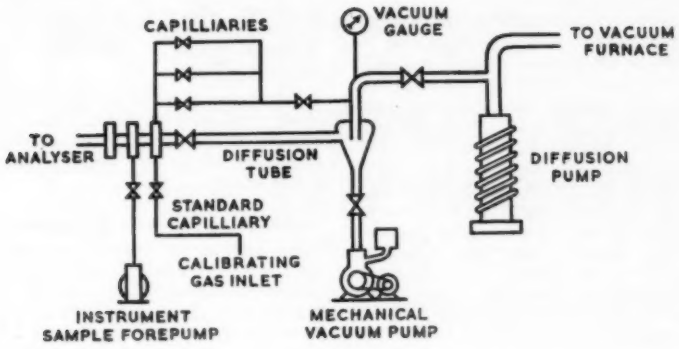
Two lead electrodes were fitted into a 250-ml Buchner flask containing dilute sulphuric acid, the connections being brass rod passing through a rubber bung. The electrodes were connected in series to a switch, a 6-volt car battery and a laboratory 20-ohm sliding variable resistance. Rubber tubing connected the side arm of the flask to a 1-litre conical flask containing the reagent and a glass outlet pipe led to a funnel and thence to process. A flow of water aided the flow of reagent and prevented hold-up of the relatively small quantities of reagent in the lines. The reagent flask was immersed in a water bath.



Operation is simple. Variation of the circuit resistance controls the rate of electrolysis of the acid and hence the production of the hydrogen and oxygen so formed. These gases in turn displace reagent from the flask and thence to the process. In practice, it is necessary to electrolyse at full current at the commencement in order to build up the initial pressure required to force the reagent up the outlet tube. This, however, takes a few minutes only and subsequent adjustment to the required rate of flow is simple.

With the low flow-rates obtainable any variation in the ambient temperature considerably affects the volume of the electrolysed gases, and thus the reagent flow-rate, and it is essential that the reagent bottle be immersed in a water bath to reduce fluctuations in temperature during day and night operation. Periodical checking is therefore necessary, unless it is possible to thermostatically control the temperature of the surrounding water bath.

Sampling System for High-vacuum Furnace Atmosphere



IN THE PRODUCTION of metals under high vacuum, the degree of refinement of a molten charge can be determined by analysing the off-gas from the vacuum furnace. The mass spectrometer is a convenient tool for carrying out such analyses.

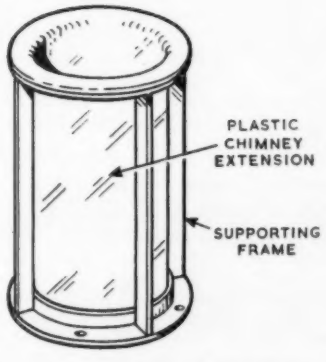
In the vacuum refining of metals, purification takes place in two steps. First, during the initial pumping down and melting, the inclusion of gaseous impurities are drawn off. Then, as the various oxides are reduced by a suitable reducing agent such as carbon or hydrogen, CO_2 or H_2O are evolved. In order to get the most out of the plant and to avoid evaporation of the more volatile metals, it is important to know when these two phases of the process are complete.

A spectrometer of a type which can sample continuously can be used, but if the inlet system is designed to sample from atmospheric pressure a modification to the sampling system is necessary. This is because furnace pressures vary within the micron-to-millimeter range.

The system outlined in the diagram (due to the U.S. Consolidated Electrodynamics Corporation) provides continuous sampling and analysis of the vacuum furnace gases at pressures ranging from 5 μ to 5 mm. The sample is drawn through the delivery tube by a mechanical vacuum pump. Either a capillary or the diffusion tube is used for introducing the samples into the instrument in conjunction with a standard 1000 μ molecular leak. A capillary is used for pressures above 1000 μ for restricting the flow enough to give a pressure of 1000 mm at the inlet to the instrument. At lower pressures the diffusion tube is used and all other connections to the molecular leak are closed. Although manually-operated valves are satisfactory, it is possible to make the operation of the sampling system automatic by using magnetic valves in conjunction with a total pressure gauge.

Cheap Chimney Extension

AT A CHEMICAL PLANT where the processes carried out give rise to corrosive fumes, the latter are exhausted through a rubber-lined chimney. An adjoining structure was noticed to be affected by the emission from the chimney and it was observed that when the chimney was up-wind of the structure fumes did, in fact, come into contact with it. For this reason, it was decided to increase the height of the chimney by a few feet so that the fumes would pass over any nearby plant. A plastics fabrication unit was on site and a lightweight and corrosion-proof extension was constructed from P.V.C. sheet, M.S. strip and two angle-iron rings in the manner shown in the accompanying diagram. The

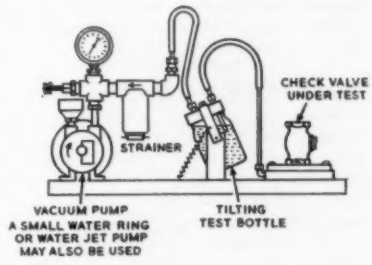


extension was bolted direct to the top of the angle ring at the top of the original chimney.

Testing for Leaks

VALVES, STRAINERS and short fabricated sections of pipework, such as manifolds, can be readily checked for leaks by means of a test rig similar to that outlined in the diagram. A component to be tested is clamped to the test table which can be fitted with a number of adapter plates to allow a range of fittings to be tested. A standard "O"-ring joint is used between the adapter plate and the test table.

When a fitting has been suitably mounted on the table the vacuum pump is started with the nozzle in the test bottle clear of the liquid. Once the maximum vacuum has been reached the nozzle is submerged by tilting the bottle. The absence or frequency of bubbling will indicate a piece of equipment which is either leak-free or



leaking. When a fabricated item is under test and found to leak, the actual faulty joint has to be found. In such cases the suspected area can be treated with a dilute ammonia solution by a small paint brush. If an indicator solution such as phenol phthalein is contained in the test bottle a change in colour will occur at the nozzle when the ammonia solution passes over a leak.

Contributions invited

THE EDITOR invites readers to submit, for possible publication in "Process Engineer's Notebook", notes on practical devices that have been elaborated on the job for improving the operation or increasing the safety of processes, or that have been extemporised in special circumstances. The contributions preferably should be of about 250-500 words, and be illustrated with a line diagram or sketch, or a photograph. A minimum of three guineas will be paid for each contribution used. They will be published anonymously or under the contributor's name, according to his wishes.

World of Chemicals

Grangemouth Phenol Plant

A new plant for the synthesis of phenol from cumene is to be built at Grangemouth, Stirlingshire, by British Hydrocarbon Chemicals, a company owned jointly by The Distillers Co., who developed the new process in Britain, and British Petroleum. The plant, which is to be completed by the middle of 1959, will use cumene made at Grangemouth from benzene and propylene, a product of the existing cracking units. In the conversion of cumene to phenol a large tonnage of acetone will also be obtained. Based on the work of the D.C.L. Research and Development Department and of its pilot-plant establishment at Tonbridge, the process has been licensed to many users abroad. The total cost of the plant and of the company's high-density polyethylene installation which is also being built at Grangemouth will be more than £8 million.

Kwinana Catalytic Reformer

Work has started at B.P.'s Kwinana refinery in Western Australia on the erection of a catalytic reformer, having a throughput of 10,000 barrels a day and costing about £A4 million. Some of the equipment is being supplied from the United Kingdom, but as much as possible is being purchased in Australia. The erection of the new unit will be supervised by British and American engineers, but a labour force of about 300 will be recruited in Western Australia. The reformer will be ready for commissioning by the end of 1958.

O.E.E.C. Nuclear Fuel Plant

The twelve member countries of the Organisation for European Economic Co-operation have set up the first joint undertaking under the newly-ratified European Nuclear Energy Agency—the European Company for the Chemical Processing of Irradiated Fuel (EUROCHEMIC). The company is to build and operate a plant for the chemical treatment of irradiated fuel (i.e., for the production of plutonium) at the Nuclear Research Centre at Moll, Belgium. At it, about 100 tons of natural or slightly enriched uranium will be treated annually, and the plant, which is expected to cost 12 million European Payments Union units of account, will probably be in operation by 1961.

U.S. Chemical Production, 1956

The production of all synthetic organic chemicals and their raw materials in 1956 was 82,121 million lb., or 9.8% more than the 74,821 million lb. produced in 1955, according to figures recently announced by the U.S.A. Tariff Commission. Total sales in 1956, of 45,518 million lb., were valued at $5.831 million, compared with 42,966 million lb., valued at $5,518 million, in 1955. The data represent totals for chemical raw materials, semi-finished and finished products, and so include duplication. The output of all finished organic chemicals and chemical products in 1956 amounted to 34,152 million lb., compared with 29,190 million lb. in 1955. The groups of chemicals that showed increases were: miscellaneous chemicals (20.6%); medicinals (13.5%); pesticides, etc. (12.6%); surface-active agents (11.4%); elastomers (11.1%); flavour and perfume materials (6.4%); plastics and resin materials (6.4%); and plasticisers 5.2%). Decreases were shown by dyes (9.8%); toners and lakes (7.8%); rubber-processing chemicals (5.6%).

Indian Antibiotics Production

Production of penicillin at the Indian national penicillin factory at Pimpri, near Poona, will be increased by 60% from October, 1958, to 40 million mega-units. The balance of 10 million mega-units required by the country will be produced in the private sector of the industry. Machinery for the manufacture of other antibiotics such as streptomycin is being installed and production will start during 1958.

Oxygen on Location

Air Products of U.S.A. has designed a series of mobile liquid oxygen plants for the Army which makes it possible to produce missile fuel at rocket-launching bases. The largest of the series has an output of 20 tons—about 80 barrels—of liquid oxygen per day. It consumes only diesel fuel, about ½ lb. of which is needed to make 1 lb. of liquid oxygen. The plants can be assembled in a few hours, according to the company, and they can operate in outdoor temperatures ranging from −25° to 125°F. The product is said to be 99.5% pure when the plants are operated at normal atmospheric pressure in air of 50% relative humidity.

Silicone Duty

The Board of Trade has imposed an anti-dumping duty on imports of silicone fluids and emulsions from France, following representations by United Kingdom manufacturers. It is the first order to be made under the Customs Duties (Dumping and Subsidies) Act, 1957.

Swedish Uranium Extraction Plans

Proposals now being submitted to the Swedish Government by A.B. Atomenergi and the State Power Board provide for the installation of a uranium extraction plant with a production of 120 tons of uranium a year, to begin by 1963. The plant would be designed on the experience of the present 5-10 tons a year plant at Kvarntorp, and its estimated cost is 115 million Kr. (£8 million). With the expenditure of a further 60 million Kr. (£4.15 million), it would be possible to utilise the sulphur content of the uranium-bearing oil-shale for the production of sulphuric acid. If this were not done, Swedish domestic production of sulphuric acid by conventional plant would have to be expanded to supply the acid required for the uranium extraction.

Texas Magnesite

Lavino are to build an $8-million magnesite plant near Freeport, Texas. It will operate a new process using magnesia from sea water and dolomite from a Texas source.

Modernising Poland's Oil Industry

As part of a scheme to modernise Poland's oil industry, the refinery at Glinik Mariampolski, South-eastern Poland, is to be rebuilt. When complete, it will have a yearly capacity of 150,000 tons, equal to that of the whole Polish oil industry at the present time. It is planned to build other refineries to enable the country to satisfy her domestic requirements between 1961 and 1975.

Indian Smokeless Fuel

The Indian Council of Scientific and Industrial Research has developed a smokeless fuel using a process that involves the combustion of volatile matter driven off from coal heated on a moving bed.

Ceylon Fertiliser Factory

Ceylon's Co-operative Wholesale Establishment has decided to establish a factory for the processing and preparation of artificial manure at a cost of Rs.15-20 million. It is the Establishment's hope to market the products for at least Rs.20 less than the present average fertiliser price of Rs.330 per ton.

New Products

The dodecyl, nonyl and chloropropyl derivatives of boric acid are being made available in development amounts by the Callery Chemical Co. of Pittsburgh. They are stated to be relatively stable to oxidation in air, to be mild reducing agents and to possess bacteriostatic, fungistatic and surface-active properties.

Tetrahydrothiophene (thiophane, tetramethylene sulphide or thiacyclopentane), a colourless liquid with a coal-gas-like odour, is being produced by Robinson Brothers Ltd., Ryders Green, West Bromwich. Its chief use is as an odorant for hydrocarbon gases, other than coal gas, used for domestic or industrial fuels. A normal dosage is ½ to 1 lb. per 1 million cu. ft of gas.

Desil, an ampholytic surface-active agent, a salt of *N*-lauryl (aminosulphonic) beta-amino butyric acid, soluble in all proportions in water and alcohols, is a new product of P. R. Masek (Research Laboratories) Ltd., 155 Fenchurch Street, London, E.C.3. The molecule contains, in about the same number, groups which are ionised respectively cationically and anionically.

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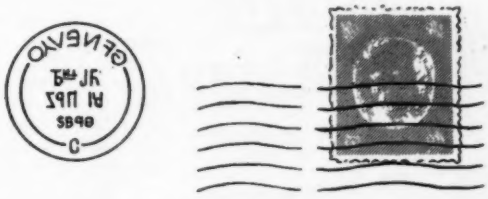

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Book Reviews

Handbook of Solvents—Volume I: Pure Hydrocarbons

by I. Mellan.

Reinhold Publishing Corp., New York. Chapman & Hall, London, 1957, 249 pp., 52s.

THIS is the first of several volumes intended to cover the composition and properties of industrial solvents. The present volume deals with over 500 solvents of the hydrocarbon type and the succeeding volumes will cover solvents belonging to other chemical groups. The author is fully qualified to write on this subject because of his very wide experience in the chemical industries.

In the first introductory section, the origin and composition of coal and petroleum are discussed. The various empirical tests and properties are then fully explained. These include: aniline point; dilution ratio; kauri-butanol solvent power; evaporation rate; odour; colour; gravity; sulphur content; doctor test; acidity test; and vapour pressure.

The remaining three sections of the book consist of tabulated properties for aliphatic hydrocarbons, aromatic hydrocarbons, and terpenes. In each of these three groups the solvents are arranged according to their distillation range, the one with the lowest initial boiling point being placed first. The various solvents are listed by their trade names, although the chemical composition is indicated for a great number of compounds. The names of the manufacturers of the solvents are also indicated. In some cases the major uses of the solvents are suggested.

The information contained in the book is derived from published scientific and technical literature as well as from information available from the manufacturers. The publication should prove indispensable to users of solvents, if only those in the American continent.

O. P. KHARBANDA

Introduction to Operations Research

by C. W. Churchman, R. L. Akcoff and E. L. Arnoff

John Wiley, New York, Chapman & Hall, London, 1957, 645 pp., 96s.

THE subject of this book, known in England as Operational Research, and abbreviated by the authors to O.R., is one of increasing importance. It is a little disconcerting to find that such a volume is described as an introduction, but the word is justified by the very large number of references for further reading, mainly articles in American journals and involving over 300 authors.

The book surveys O.R., its problems and some methods of solution. These problems are of organisation, allocation of resources, etc., all involving the search for an optimum solution or decision. To reduce the problem to mathematical terms a function, usually cost or profit and often subject to restrictive inequalities in the variables, must be constructed which is to be a maximum or a minimum. Sometimes the mathematical problem can be solved analytically or graphically, sometimes iterative or trial and error methods must be used and an electronic computer may well be called for. The authors have, in the main, developed the mathematics as required. Thus an early problem on economic lot size is easily solved by calculus, but, later, linear programming, probability theory and Monte Carlo methods become necessary. The only case in which a mathematical method is shown without reference to an industrial problem is the chapter on the theory of games.

Although the mathematics may be fairly difficult and the computation required may be long and tedious, this is clearly not the most important aspect of O.R. The preliminary analysis of the problem and its formulation, at least approximately, in mathematical terms, is the first essential, to which the first few chapters are devoted. The mathematical representation is called a model and later chapters deal in turn with models appropriate to problems of inventory (stock), allocation, waiting-time, replacement and competition (bidding for contracts). These are illustrated by numerical examples and case histories.

A final chapter makes suggestions for the setting up and training of an O.R. team. The emphasis is on a team, the contention being that, although one member must be familiar with the company's organisation as a whole, best results are obtained by the collaboration of contrasting specialists—engineer and statistician, physicist and psychologist. The book itself is a team effort from the Case Institute and there is inevitably some overlapping and repetition. In particular we are told twice that an electronic computer scanning a million permutations a second would take nearly a ¼ million years, at eight hours a day, to scan all the permutations of 20 things.

P. J. THRESHER

Polythene: The Technology and Uses of Ethylene Polymers

Edited by A. Renfrew & Philip Morgan [illegible] — Iliffe & Sons Ltd., London, 1957, 567 pp., 126s

THIS book has been jointly edited by a plastics expert and a journalist whose field is plastics, and they have been assisted by a large number of specialists, both British and American. It has been produced to indicate the knowledge which is publicly available on the subject and does this critically. In at least one instance, it is made clear that the full story has not been told because of competition. The book falls naturally into three broad divisions, namely manufacture and properties, processing techniques, and applications and prospects. Although each chapter has been written individually, the amount of overlapping is smaller than might have been expected.

There is little about this book which could give food for adverse criticism. One forms the impression that Section 1 is probably the most complete, which is what one would expect in a book of this type about an industry which is still growing. Section 2 is essentially practical, and after dealing with the design of extrusion machinery, the processing techniques are described round the various standard forms in which the polymers are normally supplied. Section 3 can only give a partially complete picture, as the list of applications widens daily. Still the picture is quite good enough to indicate to those interested whether a possible new application is likely to prove successful.

When reviewing a book for a specialised journal, the requirements of its readers must be kept in mind. At a first glance, the section on chemical plant seems sketchy but, on a second reading, this is seen to be a wrong impression. The needs of our industry are exceedingly variable and it would be difficult to collect all the information required in one short chapter. For example, one would like to see the chemical resistance of polythene included in the chapter on chemical plant, but one must and does admit that it is the more suitably placed among the properties of the substance. The guidance is there, but has to be looked for under various headings. More cross references might have been done in the applications section. Not only is this a text-book, but also a reference book and as such is cheap at the price. There is an adequate bibliography at the end of each chapter, and the index serves its purpose. That it has been produced in Britain, is one answer to the often voiced complaint that we are short of first-class technical and scientific literature.

A. WEBSTER

Nuclear Engineering Symposium Part IV

American Institute of Chemical Engineers, New York.

THIS volume contains a miscellany of papers covering such diverse subjects as the measurement of lattice constants, enamelling of zirconium, the design of testing reactors and pyrometallurgical processing. Some of the papers included are essential reading, while others are of passing interest and important only to the specialist. In this respect it is regrettable that it has been found necessary to mix papers of general interest, such as the layout and design of reactors and process plant, with specialised contributions, such as the measurement of neutron flux in critical assemblies. The reader would be better served if the material was more selective and better arranged.

Despite this criticism the volume as a whole is a useful one. A group of papers of particular interest are those covering the layout and equipment of small radiological laboratories and process plants. The Phoenix Memorial Laboratory at the University of Chicago is described and illustrates the principles involved in the arrangement of hot cells and caves. Papers by Shurkin and Kershaw discuss the ventilation problems associated with uranium

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Net Weight	23 lb.	24 lb.
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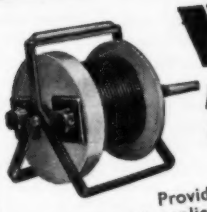

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Book Reviews (continued)

and thorium dusts in process plants and the problems arising in the handling and examination of radioactive materials. Kershaw's paper in particular gives a good résumé of American practice in the selection of caves, fume cupboards and glove boxes, with sound advice on the basic principles and design parameters.

Of the several papers included on reactor design and operation, two dissimilar contributions repay close study. J. R. Huffman reviews the operational experience obtained with the Idaho Materials Testing Reactor. This 30 mW installation has operated since 1951, and has made a material contribution to irradiation investigation. The xenon poison problem and the difficulties of measuring the flux distribution in an experimental reactor are clearly described and the conclusions are applicable to many other types of research reactor.

A totally different type of paper describes the "Engineering Design of EBR II". This 60 mW Fast Breeder reactor, scheduled for completion in 1958 at the Argonne National Laboratory, invites comparison with the recent press releases on the Dounreay Fast Reactor. The most notable difference in the American proposal is the total immersion of the core, pump and heat exchanger in a tank of liquid sodium.

A paper by Hyman and Katz entitled "Continuous Processing of Heterogeneous Reactors" suggests that the problem of fuel element canning might be eliminated by considering a heterogeneous water reactor with uncanned fuel shapes associated with continuous chemical processing of the circuit fluid. This paper might be more suited to a journal than to the proceedings of a society. It poses more problems than it answers and, in particular, hardly bothers to discuss the almost prohibitive problem of loading and unloading the fuel. A more useful and down to earth contribution comes from Wroughton, Seaman and Beeghly in a paper on "Water Technology for Primary Systems in Water Cooled Power Reactors". This appraisal gives an insight into the problems associated with the P.W.R. type of reactor and the measures required to overcome them. An intentional, although disappointing omission from the paper is a lack of discussion on the corrosive effects of water on core materials at high temperature under irradiation.

The last important grouping of papers in the Symposium is concerned with the processing of enriched fuel for advanced reactors. An important factor in the economics of power generation is the cost of enriched fissile material held up in the fuel processing cycle. Several attempts are currently being made to reduce this hold up, particularly with fast reactors. Two papers "Pyroprocessing Methods for Nuclear Reactor Fuels" and "Economics of a Fast Reactor Processing Cycle" discuss pyrometallurgical methods whereby the uranium fuel remains in its metallic state during processing. Fission products are removed by preferential transfer into contacting phases of oxides, fluorides, chlorides or metals. Since the bulk of the metal is unchanged in the process it may be refabricated quickly and a large inventory held out of reactor eliminated. The second paper by Kupp discusses the economics of the method and shows diminishing gains as the burn-up of fuel in the reactor is increased. At intermediate and low burn-up ranges the method is always likely to be more economical than the conventional processing at present employed.

As a symposium for the interested general reader and with time to explore the varied facets of nuclear engineering, the present volume can be recommended.

B. E. ELTHAM

A Guide to the Literature of Chemistry —Second edition.

by E. J. Crane, A. M. Patterson, and E. B. Marr. John Wiley & Sons Inc., New York; Chapman & Hall Ltd., London, 1957, 397 pp., 74s.

ALTHOUGH it is directed mainly to meeting the needs of chemists, and chemical engineering is treated as a poor relation, this revised second edition of the "Guide to the Literature of Chemistry" will be of unique value to chemical engineers. Sources are not only listed, but also in many cases evaluated. For completeness there are even brief references to the value of personal correspondence and of sources of unpublished material. Without being overeffusive, one can only comment that the volume completely fulfilled the claims of its title by any tests for the presence of relevant material that were applied by the reviewer. Adverse criticisms are concerned only with detail. The Russian abstract journal *Referativny Zhurnal 'Khimiya'* is perhaps underrated by muted praise. Potentially, this is the most valuable journal of its type in the world, because it is published by an organisation running a "team" of such publications and the abstractors in any one field of science pass on material to those in other fields if there is the remotest relevance. This treatment of world scientific literature as a whole has the promise of better coverage for chemistry and its border regions than the present best, which is that of the A.C.S. "Chemical Abstracts". In addition, the advice to working scientists to search for themselves rather than delegating the job is a counsel of perfection. Thorough searching is now so expert a task that large organisations have found it a sound investment to set up intelligence and records departments staffed by qualified scientists and engineers—familiar with both the subject-matter and the technique of searching. I have usually found that surveys prepared in this way never exactly meet my needs, but they give a good view of the field and can often lead with no waste of time to the source with the desired information.

The tangled subject of transliteration from non-Latin alphabets is very helpfully treated and even the filing of names beginning with one of the versions of the prefix 'Mac".

In about half a century the number of papers in chemistry and its allied subjects has increased tenfold; the number of publications must have increased by many times this factor. It is reasonable to overlook a certain amount of irritating homily (for example, "One should be prepared, persistent and resourceful") for the practical aid given by this book in steering through this embarrassment of riches to a desired piece of information.

I. BERKOVITCH

Mathematics of Engineering Systems (Linear and Non-Linear)

by Derek F. Lawden.

John Wiley & Sons Inc., New York, Methuen & Co. Ltd., London, 1954, 380 pp., 30s.

THIS book by Professor Lawden, who is well known for his researches into the mathematics of interplanetary flight, is an exposition of the basic principles of physical systems. The author defines the term "physical systems" to "embrace all complexes of interacting elements or components, such as electronic amplifiers, oscillators, electric circuits, servomerchanisms and regulators, the behaviour of each element of which may be expressed, perhaps only approximately, in mathematical form". The elements mentioned above are those which are fundamental to the design and construction of automatic control systems, and the book can therefore be regarded as an introduction to the mathematics of cybernetics.

It has long been recognised that all the automatic control systems which have been developed in the last few years, whether mechanical, pneumatic, hydraulic or electronic, are different aspects of the same basic concepts. Therefore, there is a need for a book which collects and treats as a whole the mathematics which are common to all such systems. Professor Lawden's textbook does this, and succeeds admirably in filling what was previously a gap in the literature of engineering mathematics.

N. H. LANGTON

Dechema Monographien, Band 29, Nr. 392-410

Verlag Chemie GMBH, Weinheim, Germany, 1957, 380 pp.

THE GENERAL TITLE of these series of Dechema Monographs is "research and development in the field of chemical equipment in individual essays". The present volume, No. 29, contains 19 lectures presented at the 31st Dechema Annual Meeting in 1956 and are devoted to the scientific basis for carrying out chemical reactions on the technical scale. Papers came from several European countries, including one from Professor Garner of Birmingham. They provide essential underlying analyses for attempts at the design of process equipment.

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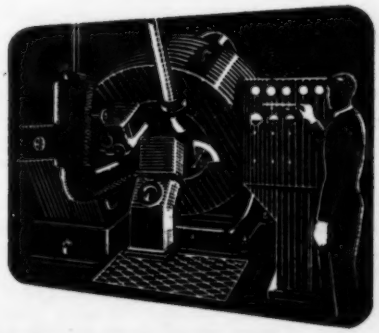

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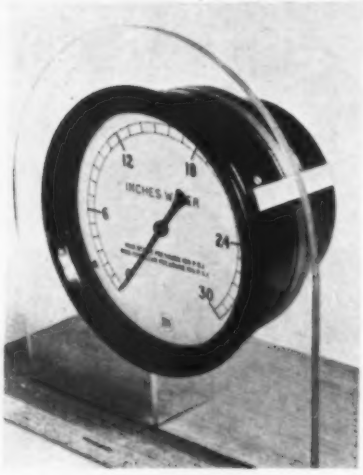
PLANT EQUIPMENT NEWS



Differential Pressure Gauge

K.D.G. have introduced a newly-designed high static differential pressure gauge suitable for use with static presures of up to 150 psi. Its main feature is that with a range 0-50 in. w.g. it can withstand the full static pressure of 150 lb. as an overload on either the high or low side of the instrument, without suffering any calibration change on return to normal conditions. For ranges 0-25 in. w.g. to 0-50 in. w.g. overloading of up to 100 psi can be accommodated. This advantage is achieved by the use of a liquid-filled collapsible system and, the makers say, it gives the instrument full protection against line fault or breakage. The instrument is particularly useful for pressurised storage tanks and flow lines. Dials for it can be calibrated in any unit required, such as pressure, volume, square root. **K.D.G. Instruments Ltd., Manor Royal, Crawley, Sussex.**

BCE 2583 for further information

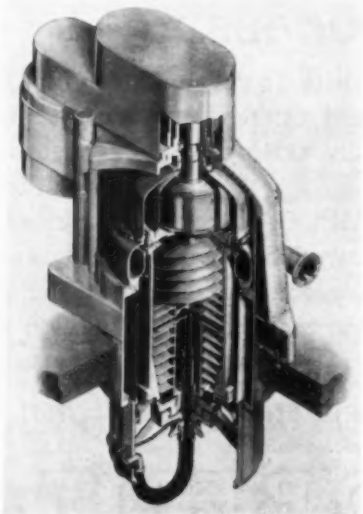
Scintillation Spectrometer

A multi-channel scintillation spectrometer for use in industrial tracer investigations is being made available by Nuclear Enterprises (G.B.). Uses to which it has been applied include the detection of deviations from the normal flow of catalyst beads in catalytic-cracking plants; the measurement of relative loads in parallel pipes in refining plants; the appraisal of baffle-plate systems designed to promote uniform flow; and the tracing of the blocking of channels in distillation units. The instruments are normally constructed in two parts—the scintillation detector which can be placed on pipes, conveyors or troughs; and the auxiliary electronics-containing ratemeter, controls, current supply, and recorder, all of which can be located up to 1000 ft away from the detector. The complete equipment, portable in a case built for hard conditions of work, could weigh as little as 40 lb., the recorder cable being carried separately. In studying flow patterns a portion of the material in flow is tracered with a gamma-ray emitting isotope and its movement is followed with the scintillometer outside the plant without disturbing operations. **Nuclear Enterprises (G.B.) Ltd., Bankhead Medway, Sighthill, Edinburgh, 11.**

BCE 2584 for further information

New Centrifuges and Decanters

New Sharples plant available in Great Britain, and shown for the first time recently at the 26th Exposition of Chemical Industries in New York, includes a high-capacity vertical decanter-type centrifuge designed to handle slurry feeds of about 200-250 gallons a minute with a solids-discharge of up to 10 tons an hour. The machine, the P-7000 Super-D-Canter (see below), is available as a pressure-tight model for operation at up to 150 psi, a vapour-tight model for operation at up to 15 psi and an open model. Special design features include the use of only a single set of seals (which are not in contact with the slurry). Only one set of main bearings is required. The company is making available, too, a high-capacity nozzle-type continuous centrifuge which also may be supplied for operation under pressures of up to 50 psi and more. A double-row nozzle system and a 30-in. diameter bowl are employed in the machine, which has a capacity of 300 gallons a minute. The third new machine being produced is a high-speed

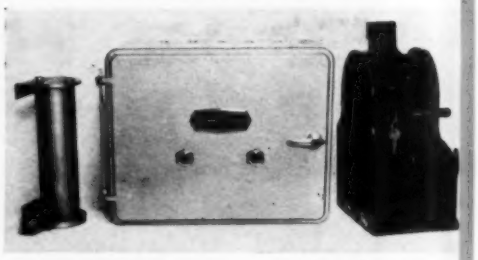


horizontal decanter-type centrifuge having a high speed of rotation (4000 rpm) and a long bowl. It offers, the makers say, very favourable throughput and clarifying capacities in the continuous processing of slurries. **Sharples Centrifuges Ltd., Tower Works, Doman Road, Camberley, Surrey.**

BCE 2585 for further information

Glass-level Measurer

Isotope Developments are now supplying complete automatic control systems for molten-glass level in furnace feeders. The systems employ the company's level indicator type 885 in conjunction with a controller and regulator for the batch charges. The level indicator consists of a water-cooled Geiger counter mounted on one side of a feeder channel and a cobalt-60 source mounted on the other side. The instrument can have a linear range of about 1 in. and, at best, a sensitivity of about 0.01 in. The response time of the instrument can be 40 seconds or 80 seconds and, as this is not unduly long compared with the



natural process lags, the output of the gauge can be fed into an automatic control system. **Isotope Developments Ltd., Beenham Grange, Aldermaston Wharf, near Reading.**

BCE 2586 for further information

Flameproof Proximity Switch

Heyes have introduced two flameproof magnetic proximity switches, designed in conjunction with Metropolitan-Vickers Electrical Co. The switches can be used for any application where the detection of a moving conveyance is necessary to initiate a sequence of operations. A permanent magnet attached to the conveyance operates an armature in the proximity switch which, in turn, operates the contacts, satisfactory operation being obtained at a conveyance speed of 50 ft per second with a maximum distance of 4½ in. between the faces of the magnet and switch enclosures. The equipment is available as a stayput type switch, which stays in the operated position after the passage of the magnet and is reset by the reverse movement of the magnet; and as a self-reset model, in which the switch returns to its initial position after the passage of the magnet. **Heyes & Co. Ltd., 11 John Street, London, W.C.1.**

BCE 2587 for further information

Industrial Stethoscope

An amplifying stethoscope for industrial use is being made by Airsonic. It will detect noises such as the sound of dry or cracked bearings and other mechanical moving parts, noises set up by metal under stress, or of water, gas or oil flowing in pipes or leaking under

We delved into Kaolin clay....

. . . and came up with this faster way to dewater it.

Kaolin clay processing is largely a matter of slurrying, settling in tanks and dewatering in large quantities.

One of the first jobs is to separate the clay into particle size ranges for various purposes and Sharples centrifuges are already widely used in this classification operation. The finest of these grades is the clay for coating fine quality printing papers. It is in the final processing of this fine fraction clay slip that we at Sharples were asked to help.

First the fine fraction slip can be flocculated by sulphurous acid, then settled by gravity to a concentration of 20% clay solids. Then comes the difficult and expensive process of dewatering by filter press to 65% solids ; especially expensive since the filter press has to be constructed of stainless steel to withstand the corrosive nature of the slurry.

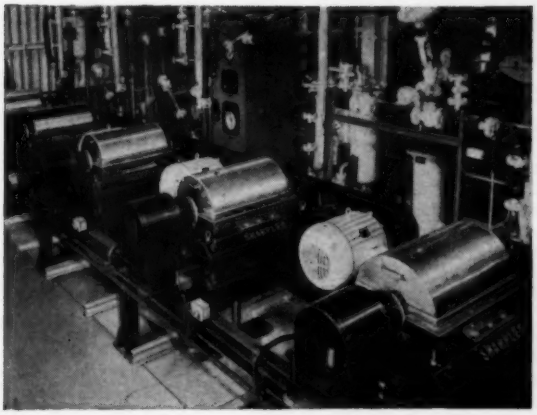
Doubling the capacity of the filters

After experimenting with various Sharples centrifuges, we found a method whereby Sharples Nozljectors would dewater the clay slurries from 20% to 40-50% solids continuously and at high throughput capacities. In this way, the clay producer could at least double the capacity of his filters by pre-thickening the clay slip fed to a filter. The Nozljector-filter press combination could then handle a given clay throughput at a substantially reduced capital investment, and with great economy in ground space requirements.

Unique Engineering Service

Kaolin clay is only one example of the Sharples Centrifugal Engineering Service in action. Whatever your separation problem may be, Sharples experts are always ready to investigate and advise. Sharples is the only concern in Britain able to offer a complete range of centrifugal machines for any separation purpose, so you can be sure of unbiased advice.

Write to us and we'll be glad to send you Report No. 2956M showing the Sharples range of continuous centrifuges. Or, if you wish, 'phone Camberley 2601 and talk to Martin Trowbridge about your problem.



An Installation of Sharples Super-D-Canters, one of the wide range of Sharples Centrifuges.

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pressure. The instrument is battery-operated and (apart from the detachable head-set) is self-contained in a pocket-sized case. It makes use of transistors and is equipped with a chromium-plated probe. **Airsonic Ltd., 14 Old Queen Street, London, S.W.1.**

BCE 2588 for further information

Electronic Recorder

George Kent's mark 2A electronic Multelec recorder, developed for and previously reserved for sale to the atomic energy industries, is now being made generally available. Its applications are temperature measurement; direct millivoltage recording; industrial measurements, depending on a radioactive source and an ionisation gauge (for example, level, thickness, density); and for research work. It has been designed primarily as a single-point indicating recorder, enabling measurement to be made at high speed. Three different types of built-in amplifier are available, the type used depending on the application—for d.c. millivolt or temperature measurement using thermocouples; for a.c.-measuring circuits of low or medium impedance; and for the measurement of d.c. voltages from sources of high resistance. **George Kent Ltd., Luton, Beds.**

BCE 2589 for further information

Pneumatic Vibrator

Recently placed on the market by Blending Machine Co. is a small vibrator known as the Blencut rapper. The appliances produce a powerful rapping vibration as opposed to a smooth vibrational resonance, and they may easily be applied to small hoppers where material has been clogging or sticking to the sides. The machines will operate at air pressures

of up to a maximum of 80 psi, and at that pressure give about 2500 strokes a minute. **Blending Machine Co. Ltd., Bond Street, Hockley, Birmingham, 19.**

BCE 2590 for further information

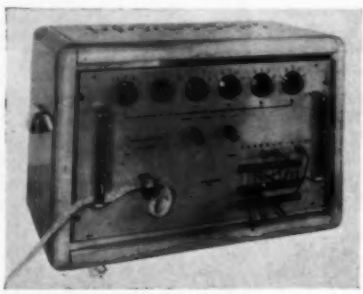
P.V.C. Ball-valves

The new Rediweld Double-Seal rigid P.V.C. ball-valve is fitted with a precision ball section which permits full opening of the valve with a 90° turn of the handle. Fluon gaskets provide the liquid-tight fit between ball and body of the valve and Fluon seals are also incorporated in the stuffing-box to prevent leakage of liquid at this point. The valves, the makers state, can be used with all inorganic acids and details of resistance to chemicals are available from them on request. A positive shut-off at full pressure or vacuum is ensured through the construction of the valve and the possibility of seizing of the valve, it is said, has been eliminated. **Rediweld Ltd., 17-27 Kelvin Way, Crawley, Sussex.**

BCE 2591 for further information

Punched-tape Reader

Dobbie McInnes have added to their range of data-processing equipment a punched-tape reader and editing unit. This equipment is primarily intended for use in conjunction with their graph-plotting equipment, but it can also operate independently of this for other purposes.



The equipment is contained in one unit which consists of a tape-feed mechanism; a decoding unit; an editing unit; a control panel and frame. The standard model can be adapted to cope with the following requirements: special codes and signals; numbers selectable from groups of more than 10; more than nine digits in a number; significant digit selection for 10 numbers instead of six as standard; the highest possible speed for specially prepared tapes, cutting out the usual editing requirements. **Dobbie McInnes Ltd., 55 Kelvin Avenue, Glasgow, S.W.2.**

BCE 2592 for further information

Ultrasonic Pipeline Testing

Mapel state that the results of tests and field trials on the application of ultrasonics to the testing of pipeline welding (on the 15½ miles of 24-in. diameter steel pipeline between Shellhaven and Romford) show that the method is very successful. The ultrasonic instrument injects electronic waves into the pipe at an angle of 40° to pipe surface. If the weld is defective some of the waves are reflected back through the probe on the cathode-ray screen, where the fault is shown as a "blip". The extent of fault can be demonstrated by movements of the probe and the degree of seriousness of the defect is determined by a "reject control". Before use, the instrument is calibrated against a weld of known quality. **Metal & Pipeline Endurance Ltd., Artillery Mansions, Victoria Street, London, S.W.1.**

BCE 2593 for further information

Temperature and Flame Controllers

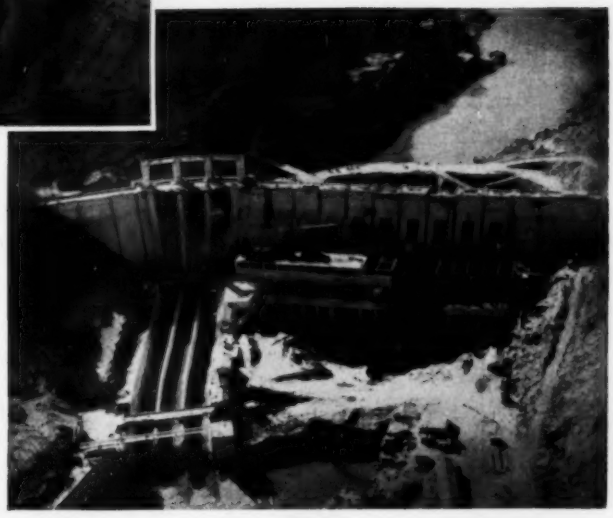
Ether Ltd have now added to their range an instrument which records the temperature of up to six points. The recording chart has a calibrated width of 6 in. and a speed of 1 in. an hour. It

runs continuously for thirty days. The company has also produced two new flame-failure controllers for gas- or oil-fired systems (see above). Type 700 is semi-automatic and the other, type 701, is a fully-automatic relight unit. The controllers embody an infra-red-sensitive photo-cell which reacts to flame failure and activates an electronic control unit to shut off the fuel supply. The controllers are sensitive to flame only and ignore radiation within the heating chamber. Also introduced is a new temperature-controller, the Thermal-trol, type 750. It employs no galvanometer, has an extremely wide range, and can control temperatures between −328°F and +1832°F (−200°C and +1000°C) for electrical, steam, gas- or oil-fired apparatus. **Ether Ltd., Caxton Way, Stevenage, Herts.**

BCE 2594 for further information

Refractory Applications

Coltrate have introduced a new range of refractory protective coatings under the name of Coltrate, R.P.C. The coatings give a gas-tight seal, resist slagging and are not readily wetted by slag. The range is as follows: Loglaze (1521-1500° to 2100°F); Midglaze (1823-1800° to 2300°F); and Higlaze (2230-2200° to 3000°F). A non-vitreous type—Nonvit—is also available, and this covers the temperature range 50° to 3500°F. A refractory mortar or bonding, patching and plugging, designed to be effective up to a temperature of 3000°F, is also being produced. R.P.C. coatings are all supplied as dry powders, which, for use, are mixed with water to a creamy paste and applied by brushing, spraying or trowelling. The coating thickness is $\frac{1}{16}$ to $\frac{1}{8}$ in. After



Setting for cement

MODERN HYDRO-ELECTRIC PROJECT

Where the great Clutha river flows south-eastwards near Roxburgh in South Island, N.Z., a new hydro-electric project is taking shape, where once gold-dredging was the only occupation. About 115,000 tons of cement are required for this scheme, and the demand is being fully met by the Milburn Lime and Cement Company which has been considerably expanded to meet this and other requirements of cement-using industries. To this seemingly-remote destination the orginal cement plant came from Edgar Allen & Co. Ltd., and also recently, additional equipment—a Stag combination tube mill, 6½′ dia. × 36′ long, for grinding raw materials and cement clinker, and a rotary dryer for lignite. A complete mill plant for firing the rotary kilns from the British 'Rema' Manufacturing Co. Ltd., too, participates in the venture.

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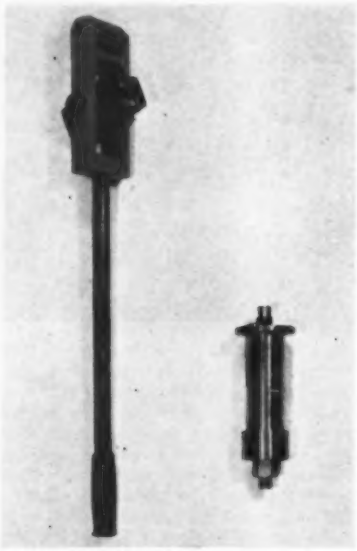
application, the furnace is fired and the temperature steadily increased to the point of vitrification. **Coltrate Ltd., 35 New Broad Street, London, E.C.2.**

BCE 2595 for further information

Tube Extractor

The new T.57 tube extraction unit by Baxter has been designed for the extraction of non-ferrous tubes between ½ in. and 1 in. o.d. from condensers, heat exchangers and similar plant. It consists basically of a threaded core of high tensile steel, at one end of which is a mandrel which is expanded by tightening a nut on the core. A steel neck fits over the core which, however, projects to allow another nut to be fitted. A ratchet is then used to turn the core and so to withdraw the tube a few inches. In many

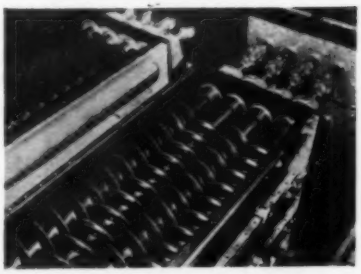


cases this initial extraction is sufficient to allow the tube to be freely withdrawn by hand. The extractor has been well tested in the company's own marine contracts department. **Baxter Brothers Ltd., Collingwood Buildings, Newcastle on Tyne, 1.**

BCE 2596 for further information

Conveyor Heat Exchanger

The Holo-Flite processor which, under licence, is to be manufactured and marketed by the Holdan division of Holmes is a heat exchanger, which, the makers point out, combines maximum heat-exchange area with minimum space requirements. Designed as a screw conveyor with helical, hollow flights through which the heat-transfer agent is circulated, it moves the material to be heated, cooled or dried at a uniform, predetermined rate. In an installation cooling 25 tons of solar salt per hour from 250° to 130°F, the machine, complete with all driving gear, water connections, etc., required only 300 cu. ft of space. The hollow Syncro-Screws incorporated in



the machine are intermeshed and grouped in multiples of two. Generally, there are two or four screws in one unit. The heat-exchange agent circulates through every flight and through the hollow shafts on which the flights are mounted. The rate of flow through the shafts and flights is controlled, as is also the temperature of the heat-exchange agent. The rotating flights are mounted in troughs. The assembly of screws, trough, bearings and drive forms the basic unit, and several units may be arranged horizontally, vertically or in both dimensions to form a multi-unit. The overall length of a unit varies from 15 to 33 ft. Operational figures for, respectively, throughput, and inlet and outlet temperatures quoted by the makers include the following: heating ammonium nitrate: 8000 lb. hr, 68°F, 104°F. Drying polyethylene resin: 2000 lb. hr, 104°F, 212°F. Cooling ammonium sulphate: 12,500 lb. hr, 150°F, 90°F. **Holdan Engineers (London) Ltd., 119 Victoria Street, London, S.W.1.**

BCE 2597 for further information

Hose Coupling

Airtech have made available a new hose coupling for use with low- and medium-pressure compressed air and fluids. The Free-end coupling, as it is called, forms a one-piece unit which needs no dismantling. No preparation of the end of the hose is required in its use and no tools are required for fitting or removing the hose. For a given inside diameter of hose a coupling can accept varying wall thicknesses. Two types of coupling, manufactured in nylon and suitable for working pressures up to 250 psi, are available. Type D is for joining two lengths of rubber or plastic hose together, and type S has one end threaded for attachment to a tool, or to a supply point where the coupling can remain permanently. Similar couplings manufactured

in brass will shortly be available. **Engineering Division, Airtech Ltd., Haddenham, Bucks.**

BCE 2598 for further information

Dewpoint Meter

The Alnor dewpoint meter is now being manufactured under contract in Great Britain by C. F. Casella & Co. It is a portable, self-contained instrument, manually operated and designed for the measurement of the water-vapour content of air or any other gas having a dewpoint within the range −80°F to room temperature. Originally it was developed by the Illinois Testing Laboratories Inc., of Chicago. The sale and distribution of the instrument is being carried out by **Electric Resistance Furnace Co. Ltd., Netherby, Queens Road, Weybridge, Surrey.**

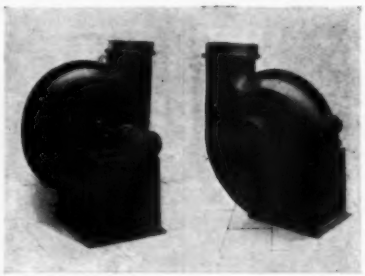
BCE 2599 for further information

Plate-and-frame Filter Presses

A new wide range of plate-and-frame filter presses produced by F. H. Schule G.m.b.H. of Hamburg has just been introduced to the British market by Durham Raw Materials. The presses, manufactured in Schule's own foundry and machine shops, are produced in sizes extending from a four-chamber laboratory model in Plexiglass to multi-frame models with electro-hydraulic closing and opening devices. **Durham Raw Materials Ltd., 1-4 Great Tower Street, London, E.C.3.**

BCE 2600 for further information

Moulded P.V.C. Exhaust Fans



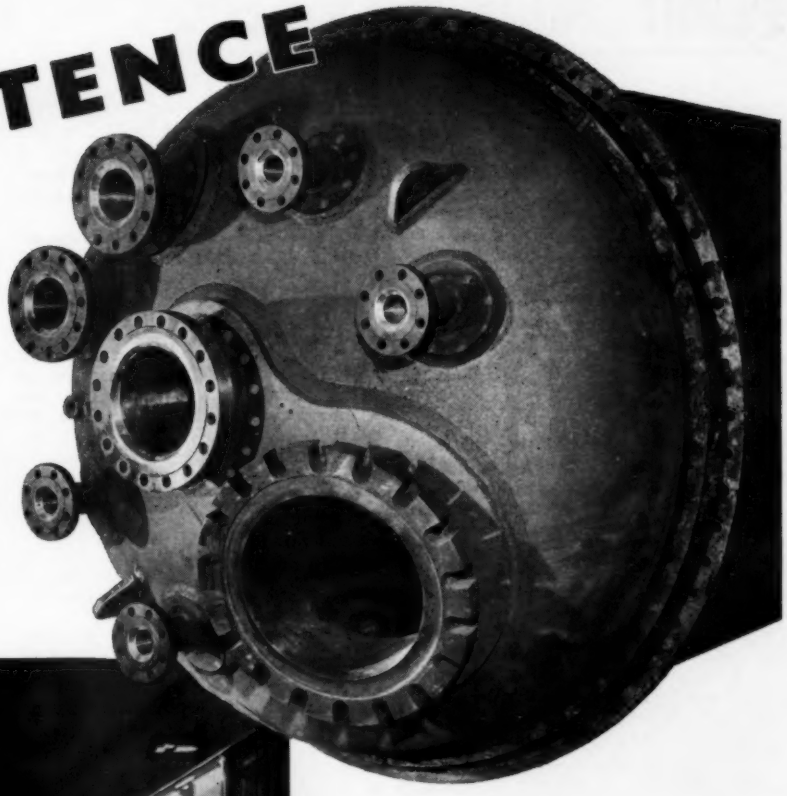
In conjunction with Acalor, Sturtevant have produced a range of moulded P.V.C. fans based on their original Monogram series. They have been designed particularly for exhausting corrosive fumes, and are fitted with moulded casings and a fully-moulded P.V.C. impeller, thus permitting higher operating speeds and efficiencies than can be obtained with fabricated fans of this type. Two sizes are now available and larger sizes are coming forward shortly. **Acalor (1948) Ltd., Kelvin Way, Crawley, Sussex.**

BCE 2601 for further information

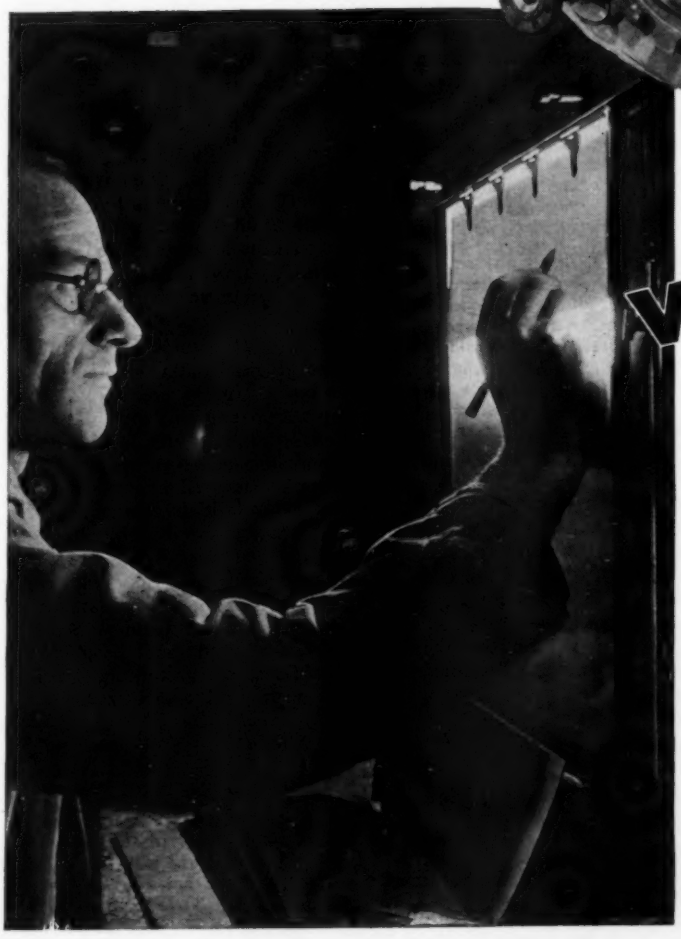
Straight-through Diaphragm Valves

A new range of straight-through diaphragm valves, type KB, has been made available by Saunders to replace their type K valve. The new model contains the features of the previous design, but has a higher working pressure, less weight and greater uniformity of cross-sectional area. K-type bonnet assemblies

COMPETENCE



Head of a 6 ft. dia. Autoclave, spun on the Harvey "Rotarpress" from a stainless steel disc 1⅝ in. thick.
Designed for a working pressure of 500 lbs./sq. in.



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PLANT EQUIPMENT NEWS

and diaphragms have been matched to a redesigned body of the next size larger, e.g., a 2-in. K bonnet and diaphragm is now combined with a new 2½-in. KB body to form a 2½-in. KB valve. This matching has produced a dimensionally full-bore valve, and flow tests, the makers say, have shown results comparable with the best known for this kind of valve. **Saunders Valve Co. Ltd., Cwmbran, Mon.**

BCE 2602 for further information

New Coatings

Corrosion Ltd. announce the introduction of Glostack, a new high-temperature metal coating designed for the protection from rust of steel chimney stacks, furnace doors and other steelwork subjected to high operational temperatures. Experience during development, the makers say, has shown that the product will withstand exposure to temperatures of well over 800°F for long periods. The company is also making available Polybond, a plastic adhesive and bonding agent designed for building and industrial uses. It is an emulsion, and is stated to be waterproof, resistant to oil, grease, petrol, moulds and fungi and to a number of chemicals. **Corrosion Ltd., 16 Gloucester Place, London, W.1.**

BCE 2603 for further information

Quality Controller

Wayne Kerr have designed a range of adaptors which enable the company's universal bridge to be applied to a wide range of chemical measurements for process and quality control. The measurements are made with the use of non-contacting electrodes, and as the adaptors can be employed at a considerable distance from the bridge the examination of flowing liquids is simply undertaken. Needle electrodes have been designed, originally for the examination of salt penetration of cured bacon, but useful results have been achieved using them for the quality control of pastes and creams. A series of capacitive-coupling cells with non-contacting electrodes is under development. **Wayne Kerr Laboratories Ltd., Chessington, Surrey.**

BCE 2604 for further information

High-temperature Heating Plants

Rose, Downs & Thompson have been licensed by Hch. Bertrams Ltd., of Basle, for the design, manufacture and supply of high-temperature heating plants using the Bertrams system. The system makes use of a closed circuit of heated Dowtherm automatically controlled to within 1-2°C of any predetermined temperature up to 370°C. It enables a series of vessels to operate simultaneously at various temperatures between 60°C and 370°C, using one boiler in a closed circuit without loss of heating fluid. The pressures within the circuit never rise above 80 psig, so that the majority of existing plants can be coupled up without alteration. The plants are available in a number of sizes so that it is possible to obtain heating plants which are practically "hand-tailored", it is said, for particular processes. **Rose, Downs & Thompson Ltd., Old Foundry, Hull.**

BCE 2605 for further information

Other Items of Interest

Scotmec have introduced the Mill-N-Mix feed mixer for milling and mixing balanced animal rations. It incorporates a high-performance vertical mixer and an enclosed 3-h.p. motor mounted to the mixer base. **Scotmec Ltd., Ayr.**

BCE 2606 for further information

Vacuum tray-driers coated on the interior with epoxy resin paint are being added to the range of equipment available from **Apex Construction Ltd., 15 Soho Square, London, W.1.**

BCE 2607 for further information

The New Welbeck Floor Master industrial vacuum cleaner models are fitted with two or three detachable twin-turbine power units. **New Welbeck Ltd., Moulescoomb Way, Brighton, 7.**

BCE 2608 for further information

The present address of Dallow Lambert & Co. Ltd. is Thurmaston, Leicester, and not as stated in the announcement in *British Chemical Engineering*, December, 1957, p. 690.

BCE 2609 for further information

Now available in Great Britain is a laminated wood flooring called Permadec, a material developed on the Continent, where it has been in use for more than 20 years. Suggested applications for industry include decking in chemical plant where corrosion problems are acute. **Permali Ltd., Bristol Road, Gloucester.**

BCE 2610 for further information

Pascall are marketing a cascade sample divider, a laboratory unit for quickly obtaining a small representative sample of bulk powder for sieve analysis of the particle size range. **Pascall Engineering Co. Ltd., Gatwick Road, Crawley, Sussex.**

BCE 2611 for further information

Paripan have announced a new product, Parinium Primer, Parinium Silver Finish, which is an aluminium-based material having anti-rust and corrosion-resisting qualities. **Paripan Ltd., 1 Sherwood Street, London, W.1.**

BCE 2612 for further information

F. H. Bourner are the sole concessionaires of the Mechtrical anti-burst system. The system uses a fine, specially-designed tubing which, when inserted into cold water pipes, ensures that the expansion of water on freezing is absorbed by the tube and not exerted on to the walls of the pipe. **F. H. Bourner & Co. Ltd., Crawley, Sussex.**

BCE 2613 for further information

New Publications

A new bulletin issued by Horwitch-Smith gives details of this company's oxythene pipe fittings which, they state, are now available in a complete range of sizes and types. **Horwitch-Smith & Co. Ltd., Pensnett, Brierley Hill, Staffs.**

BCE 2614 for further information

A leaflet (No. 1524) describing a molten-metal Mopump has been issued by Rhodes, Brydon & Youatt Ltd. These vertical pumps have been developed to handle relatively low melting point metals such as tin, lead, sodium, etc. Copies from **Rhodes, Brydon & Youatt Ltd., Gorsey Mount Street, Stockport.**

BCE 2615 for further information

Publication No. O51 describes the Megger insulation tester manufactured by **Evershed & Vignoles Ltd., Chiswick, London, W.4.**

BCE 2616 for further information

A brochure describing a low-temperature oxidation process by which combustible fumes, vapours, gases and odours of an organic nature are converted to odour-free gases is described in publication No. 70 produced by **W. C. Holmes & Co. Ltd., P.O. Box No. B.7, Turnbridge, Huddersfield.**

BCE 2617 for further information

The Consolidated Pneumatic Tool Co. Ltd., have recently issued the first section of their accessories catalogue. This new publication is a ten-page brochure which gives full details of hosepipes, hose fittings, water hoses for pneumatic pumps, connectors, spuds, nipples, couplings, clamps, Hercules repair clips, adaptors, bushings and air-line lubricators. Information is also included on a pocket air-line testing gauge and a pneumatic duster, together with details of automatic drain taps, air cocks, hoseclamps and three-way couplings. All these items are clearly set out, illustrated and specified in detail. **The Consolidated Pneumatic Tool Co. Ltd., 232 Dawes Road, London, S.W.6.**

BCE 2618 for further information

George Kent have recently issued a leaflet (publication 283) giving details of their *P* orifice fitting. Publications illustrating and describing other Kent orifice fittings will be supplied on request to the manufacturers. A further publication (275) gives details of the company's Dall tube for measuring the flow of water, compressed air and low-pressure air. **George Kent Ltd., Luton, Beds.**

BCE 2619 for further information

"Films and Automation" is the title chosen by the Scientific Film Association for their latest publication which records the activities of meetings recently held on automation and which were illustrated with films from North America, the U.S.S.R. and Great Britain. Price 3s. 6d. from the **Scientific Film Association, 164 Shaftesbury Avenue, London, W.C.2.**

BCE 2620 for further information

BCE 2539 for further information

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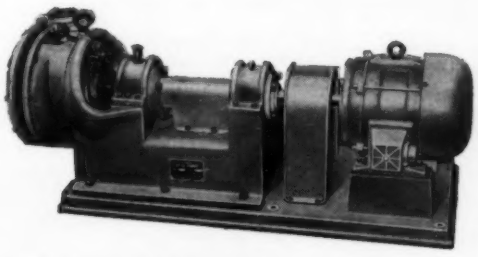

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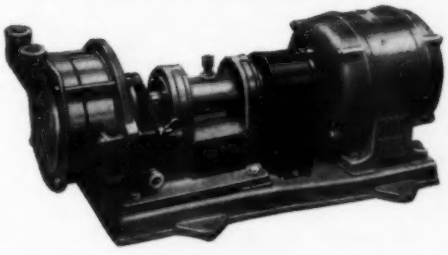

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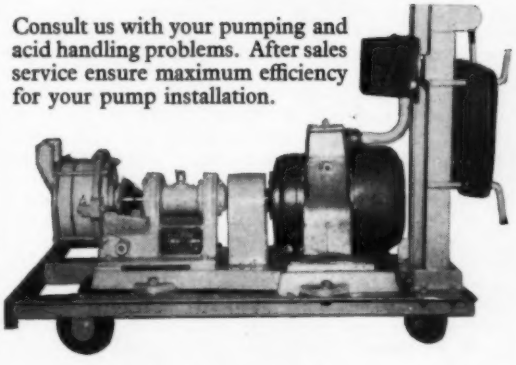

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Month's News in Brief

British Trade Fairs

An inquiry just completed by the Federation of British Industries at the request of the President of the Board of Trade into the future of trade fairs in Britain shows that the vast majority of trade associations are opposed to the development in this country of a general international fair covering a wide range of industrial products, similar to those held in most European countries. They favour, instead, the continued development of specialised fairs which cover the products of a particular industry.

The inquiry also revealed that opinion was about equally divided among those trade associations which expressed a view, on the question whether specialised trade fairs in Britain should be national, in that they should be open only to firms showing products of U.K. origin, or international. This corresponds with the facts of the present situation. Of the 60 specialised fairs held each year in this country, about half are national and the other half international.

The reason for the F.B.I. inquiry was because the London branch of the British Industries Fair had ceased to operate; that the Birmingham Chamber of Commerce had announced that there would be no Birmingham B.I.F. next year and that it (the Birmingham Chamber of Commerce) would no longer be responsible for such a fair on the existing all-British basis. It had, therefore, asked the Government to go into the question of organising an international fair. The results of the F.B.I. inquiry have been communicated to the President of the Board of Trade and to the Birmingham Chamber of Commerce.

Now that it is known that industry does not want a large general fair, the F.B.I. feel that it is possible to consider what is required in order to give specialised fairs the modern and up-to-date exhibition facilities which they need. The F.B.I. now proposes to institute a further inquiry into this aspect of the problem.

Industrial Trade Fairs

A new company under the title of "Industrial and Trade Fairs Ltd." has been formed jointly by the *Financial Times* and the George Newnes group.

The company is to promote industrial exhibitions and trade fairs in this country and abroad, which, it is hoped, will help to foster new markets for British enterprise that are being opened up by developments in Europe and elsewhere. The exhibitions will have the backing of the *Financial Times* and of the technical and trade publications of Temple Press Ltd. and the National Trade Press Ltd., both of which are members of the George Newnes group.

As a general rule, the exhibitions will be sponsored by the new company and the organisation will be carried out by Trade Fairs and Promotions Ltd., another member of the Newnes group with many years of experience in exhibition work. In addition to dealing with major industries, the new company will also sponsor exhibitions of smaller and more specialised industrial activities, many of which have made marked progress in this country since the war. It is also understood that not only is Industrial and Trade Fairs Ltd. planning to launch new exhibitions, but its resources are available to undertake the organisation and promotion of existing exhibitions on behalf of trade federations and associations where it is considered that this additional publicity organisation could render service to the federation concerned.

Chairman of the new company is the **Earl of Drogheda**, O.B.E. (managing director *Financial Times*), and the other directors are **Mr. V. G. Sherren** (managing), **Mr. E. N. Adlington** and **Mr. P. H. Baker** of the George Newnes group, and **Mr. T. S. G. Hunter** and **Mr. I. C. Trafford** of the *Financial Times*. The registered offices are Drury House, Russell Street, London, W.C.2. Tel.: TEMple Bar 3422.

News Briefs

Work on a new plant for the production of an important aviation gasoline-blending component is now in progress at Stanlow Refinery, Cheshire. Costing £800,000 and designed by Universal Oil Products Co., this new Udex Unit, as it is called, is expected to be in operation by mid-1958.

The Kalinga Prize for the popularisation of science, offered annually by the United Nations Educational, Scientific and Cultural Organisation, has been awarded for 1957 to **Bertrand Russell**, British philosopher, scientist and writer. The Kalinga Prize of £1000 sterling is offered for the purpose of recognition of the work of leading interpreters of science and of strengthening links between India and scientists of all nations.

A contract worth £80,000 for the supply of chemical plant has been placed with Thompson Bros. (Bilston) Ltd., by Courtaulds Ltd. The chemical plant is for Courtaulds' new factory in Grimsby, which has been specially designed for "Courtelle" production.

To extend their activities in new work in the chemical engineering and automatic control fields, Constructors John Brown Ltd. have recently established a research and development station at Leatherhead, Surrey. **Dr. H. H. Rosenbrock** has been appointed research manager at the station, and **Mr. N. Wyn Roberts** is in charge of work on the chemical engineering side. The company's research and development activities as a whole are managed by **Mr. Campbell Secord**, who will be responsible for the general direction of work at the station.

The 8000 sq. ft extension to the factory of Ferro Enamels Ltd. at Wombourn, Wolverhampton, is now nearing completion, and will, it is reported, house one of the most up-to-date colour oxide plants in Europe. The total cost of new plant and equipment is said to be £75,000. The company states that new flow-production methods have been utilised in the plant and these, coupled with the latest type of processing equipment suitably located for efficient layout, should increase output by 400%.

The Engineering Apprentice School recently built at the Billingham factory of Imperial Chemical Industries Ltd. was officially opened last month by Sir Edward Boyle, Parliamentary Secretary to the Ministry of Education.

The new school building was designed by the division's chief engineer's department. Modern in style, it has light, spacious rooms, bright colourings and contemporary furniture, and the school provides complete facilities for the training of apprentices in fifteen trades. Practical training is given mainly in three large bays, in the first of which the apprentices learn the use of basic tools and techniques; in the second they make their first acquaintance with machine operation; the third is a production bay.

The Governing Board of the National Institute for Research in Nuclear Science announce that W. E. Chivers & Sons Ltd. have been awarded a £1 million contract for the construction of the main buildings for the Institute's new Rutherford High Energy Laboratory on a site adjacent to the Atomic Energy Research Establishment at Harwell. It will be recalled that it was announced on March 14 last that the Governing Board of the Institute had been appointed with **Lord Bridges** as chairman. On October 7, 1957, it was stated that the contract for the magnet yoke had been placed with Joseph Sankey & Sons Ltd., who will supply the 340 steel blocks, each weighing 20 tons, at a total cost of over £1,250,000; the special steel will be supplied by the Steel Company of Wales.

As from January 1, 1958, the London address of the Pulsometer Group changed to Pulsometer House, 20/26 Lamb's Conduit Street, W.C.1. Tel.: HOLborn 1402.

Kent Continental Société Anonyme, the Belgian subsidiary of George Kent Ltd., has moved into larger premises. The new address is 27 rue Paul-Emile Janson, Brussels. Tel.: Brussels 38.31.84 and 37.78.15.

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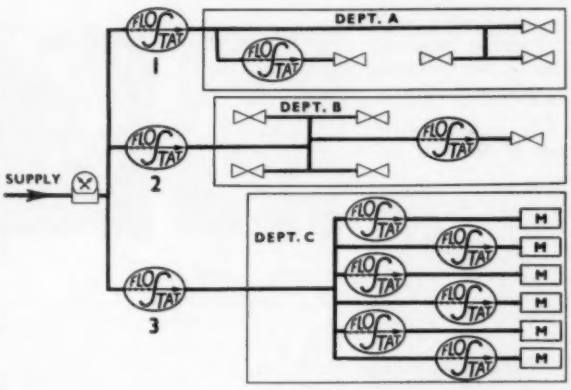

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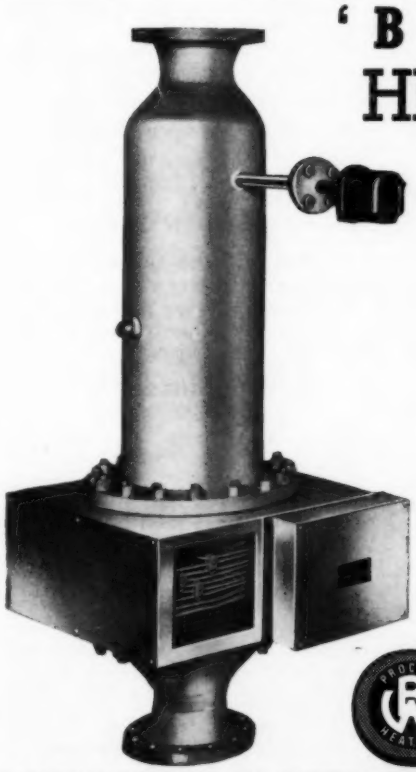

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People in the News

Recipients of Honours published in the New Year list include: *Knights Bachelor:* **Prof. C. K. Ingold**, professor of chemistry, University College, London; **W. J. Worboys**, chairman, Council of Industrial Design, director, I.C.I., vice-president, Associated British Chemical Manufacturers.

Order of Bath, K.C.B.: **H. W. Melville**, Secretary, Department of Scientific and Industrial Research.

Order of the British Empire, K.B.E.: **N. A. Gass**, C.B.E., M.C., chairman, British Petroleum. *C.B.E.:* **E. H. Ball**, managing director, B.T.H., Rugby; **Prof. H. J. Emeléus**, professor of inorganic chemistry, University of Cambridge; **C. Metcalfe**, managing director, E.M.I. Electronics Ltd.; **R. W. West**, principal, Battersea College of Technology; **J. Wilson**, M.C., director of research, British Rayon Research Association. *O.B.E.:* **S. Alty**, works manager, Brine and Water Works, Alkali Division, I.C.I.; **J. F. Gillies**, vice-principal, Belfast College of Technology; **H. Seligman**, deputy chief scientist, Head of Isotope Division, Harwell. *M.B.E.:* **E. F. Burford**, manager, Heavy Construction Department, G. A. Harvey & Co. (London) Ltd.; **S. F. Hathaway**, senior experimental officer, National Physical Laboratory, D.S.I.R.; **Miss I. M. Slade**, information officer, British Iron and Steel Research Association.

W. J. Worboys

H. W. Melville

N. A. Gass

E. H. Ball

C. Metcalfe

J. Wilson

Dr. P. V. Clifton, formerly chief chemical engineer to the A.P.V. Co., has joined the Brook Street office of Sharples Process Engineers Ltd.

Dr. P. V. Clifton

Sir Alexander Fleck

Sir Alexander Fleck, K.B.E., F.R.S., chairman of Imperial Chemical Industries, has been installed as president of the British Association for the Advancement of Science for the year 1958 (see "Digest", page 62).

Mr. P. Baines, previously company secretary, has been appointed a director of Marchon Products Ltd., and of its associated companies, Solway Chemicals Ltd. and Astoria Shipping & Transport Co. Ltd. His duties will be primarily administrative and will include purchasing. He will continue to hold the appointment of secretary to the three companies.

Albright & Wilson Ltd. announce that **Mr. Kenneth Wilson**, having reached the age of 72, has decided to retire from the board of the company on January 22, 1958. This will be the fiftieth anniversary of the date he joined the company. He became a director in 1910 and has been chairman since 1932. In appreciation of his long and devoted service to the company, the directors have invited him to accept the honorary title of president of the company and he has agreed. Mr. Wilson will be succeeded as chairman of the company by **Mr. S. Barratt**, who joined the company in 1932.

The death occurred in London on January 4 of **Viscount Waverly,** O.M., F.R.S. As Lord President of the Council from 1940-43, he was the man responsible for the new atomic bomb project and he created the directorate of Tube Alloys. In 1945 he was appointed chairman of the advisory committee for the industrial and military uses of atomic energy.

Meetings of the Month

Institution of Chemical Engineers

January 21. Whole-day Symposium on Nuclear Energy. At the Hoare Memorial Hall, Church House, London, S.W.1.

January 21. *North Western Branch:* At Blossoms Hotel, Chester. "Production of Boron-10 by Distillation of Boron Trifluoride". **7 p.m.**

January 22. *North Western Branch:* At Chemistry Department, Lecture Theatre, Leeds University. Paper on "Heat Transfer Analogues". **7 p.m.**

February 1. *Midlands Branch:* At Midland Institute, Paradise Street, Birmingham. "The Choice of Materials for Sugar Refining Plant". **2.30 p.m.**

February 4. *London Branch:* At the Geological Society, Burlington House, London, W.1. "Mass Transfer between Fluidised Particles and a Gas", "Sedimentation and Fluidisation", "The Turbulent Flow of Suspensions in Tubes". **5.30 p.m.**

February 18. *Manchester Branch:* At Reynolds Hall, College of Science and Technology, Manchester. Symposium on "Tools of Chemical Production Management". **3 p.m.**

Society of Instrument Technology

January 23. *Tees-side Section:* At Cleveland Scientific and Technical Institute, Corporation Road, Middlesbrough. "Strain Gauges and their Industrial Application". **7.30 p.m.**

January 28. *Data Processing Section:* "Digital Codes in Data-Processing Systems". **7 p.m.**

January 29. *Chester Section:* At the Board Room of the Chester and District Hospital Management Committee, 5 Kings Building, King Street, Chester. "Industrial Applications of Radio Isotopes". **7 p.m.**

February 7. *Cheltenham Section:* At the Rotunda, Cheltenham. "Process Control in the Chemical Industry". **7.30 p.m.**

Institution of Civil Engineers

January 28. At the Institute, Great George Street, Westminster, London, S.W.1. Discussion: "Disposal of Town's Waste". **5.30 p.m.**

Institution of Mechanical Engineers

January 29. *Education Group:* At 1 Birdcage Walk, Westminster, London, S.W.1. "To What Extent Should Students be Penalised for Bad English in National Certificate Exam. Papers?" **6.45 p.m.**

Society of Chemical Industry

February 18. *Chemical Engineering Group:* At Society of Chemical Industry, 14 Belgrave Square, London, S.W.1. "Industrial Uses of CO_2." **5.30 p.m.**

Society of Glass Technology

February 13. *North Western Section:* At the Gamble Institute, Victoria Square, St. Helens. "The Clean Air Act and the Glass Industry." **6.15 p.m.**

British Institution of Management

January 6. At Caxton Hall. One-day Conference. "Work Study and Continuous Manufacture", "Design of Plant", "Statistical Methods and Work Study", "The Planning of Production", "Planned Maintenance", "Construction Planning" and "An Evaluation of Work Study". Commencing **9.30 a.m.**

January 20 to 24. John Diebold & Associates Inc., New York, with the support of the British Institute of Management. At The Washington Hotel, Curzon Street, London, W.1. "Automatic Data Processing."

Scientific Film Association

January 23. At Mezzanine Cinema, Shell-Mex House, Strand, W.C.2. "Health and Safety in Industry". **6.30 p.m.**